THE AMERICAN ENCYCLOPEDIA AND DICTIONARY OF OPHTHALMOLOGY

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ASSISTED BY A LARGE STAFF OF COLLABORATORS

FULLY ILLUSTRATED

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Phonoscope to Protozoic Disease of the Lids

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Phonoscope. See **Optophone.**

Phonoscopy. See **Optophone.**

Phorcydes. In Greek mythology, daughters of the sea-god, Phorcys, by his sister, Ceto. They had only one eye and one tooth among them, and these they held in common. The Phorcydes were also called *Graiæ* (q. v.).—(T. H. S.)

Phoria. The direction or tendency of the visual lines, as in orthophoria, heterophoria, exophoria, etc.

Prentice Phoria Indicator.

Phoria indicator. This useful device invented by Charles F. Prentice is an improvement upon the author's well-known phorometric chart.

The original phorometric chart consisted of a blackboard, for which the Bausch & Lomb Optical Co. has now substituted a cross, consisting of two hollow metal chambers about 20 inches long, intersecting each other centrally at right angles. Within, and immediately in the center of the intersecting chambers, there is an electric lamp placed directly behind a small red glass disc, the same lamp serving to illuminate,

somewhat less vividly, eight vertically and eight horizontally arranged green glass discs, which are each 6 cm. apart, so that each interval of space between the centers of the colored discs represents 1△ at 6 meters' distance. Estimates of prism-dioptral deviation made at lesser distances than 6 meters are absolutely unreliable and incorrect. (See Vol. X, page 7275.) In connection with this apparatus, which is strictly intended only to determine hyperphoria that is to be corrected by prisms, the author preferably uses a +12 D. cylindric lens, in order to produce a much heavier and more readily recognized line of light than is commonly observed through the Maddox rod.

The patient being directed to look through his *distance* glasses at the central red light with both eyes—while the cylindric lens is placed by the operator, first vertically and then horizontally before one eye—will be able to indicate promptly any displacement of the red line of light from the center, by stating through which of the green discs the red line seems to pass. For instance, should the red line of light appear to pass horizontally through the first green disc *above* the center, when the cylindric lens is properly placed before the patient's right eye, the operator will at once decide that a prism of 1△, placed with its base up before the patient's right eye, should cause the red line to drop one point to the center, thus counteracting the manifest hyperphoria. Should further deviation persist after this prism is introduced, however, it would merely suggest that there is, at least temporarily, more hyperphoria latent. The author's experience leads to the conclusion that an attempt should at first be made to correct *only the manifest hyperphoria* through spectacles.

It is, of course, of the utmost importance that the centers of the distance glasses worn during the test should be carefully adjusted with respect to their interpupillary distance and elevation. When the vertical deviation of the visual axes exceeds the amount provided for by the apparatus (4△), correction by prisms is more or less uncertain, owing to the phenomena of internal reflection and spectral color generally apparent in prisms of high power.

Lateral deviations of the visual axes are to be similarly ascertained by means of the horizontal green discs on the apparatus, though great caution should be exercised in reaching conclusions respecting them. Besides, as before stated, in such cases prismatic corrections of sufficient power to be theoretically effective are both cumbersome and generally unsatisfactory in practice.

Phorometer.* This instrument, as we know it today, did not spring full fledged from the brain of any one investigator or experimenter in the field of ophthalmological science or physiological optics. It is

the result of the experiences, efforts, investigations, devices and suggestions of many enthusiastic workers and students in optics, physiology and ophthalmology, as applied to the functions and mechanism of the ocular muscles. Fundamentally, it is based upon the laws of light from a purely physical standpoint as modified by physiology and applied by ophthalmology; hence we find that workers and students in each of these special fields have contributed here and there to its evolution and finally brought it to its present high state of development of well nigh perfection.

The gross errors of ocular muscle imbalance, that is strabismus, in its various forms, were observed centuries ago, but the full significance was not appreciated nor understood until the early part of the nineteenth century, when the study of anatomy had uncovered the cause and Dieffenbach introduced the remedial measures based upon a real understanding of this cause.

Operations prior to this time had been done for the relief of such conditions, but not intelligently or scientifically.

Errors of imbalance, which were not manifest, were unobserved by the great mass of workers until von Graefe began the study of a latent form of strabismus which had not been recognized and which he termed insufficiency of the internal recti. His observations were made upon patients who were unable to converge in the near, while there was seeming balance for distance; this he termed latent strabismus or insufficiency of the internal recti. These observations were evidently made upon myopic patients. This lead him to place a prism of 15° base down before one eye, while the patient was instructed to observe a card held at the reading distance, on which was a dot, through which passed a vertical line. If the two eyes then saw two vertical lines and a dot on each, the upper line and dot being to the opposite side, he concluded that there was insufficiency of the internal rectus of the eye before which the prism was held, this insufficiency being measured by the prism which, held in a horizontal position would bring the two lines into one continuous line, with two dots thereon, one above the other.

It is doubtful if von Graefe grasped the full significance of his important observations, which were really fundamental.

Thus was laid the foundation upon which has been built, from time to time, the now complex instrument which we of today know as the phorometer.

While this foundation was good, yet the general trend of thought and investigation remained too circumscribed from 1857 for a quarter of a century, during which time the workers in this field contented

themselves with the study of the infirmities of the internal recti and their anomalies, seemingly oblivious of the fact that the external recti had any part to play in this category, or that the superior and inferior recti or the obliques, were to be considered as playing any rôle, as a part of the extraneous muscular system. This only goes to show that progress up to this time was very slow, because no single mind had fully grasped the significance of the subject. This was practically the condition of this most important field, when Stevens began his studies of the ocular muscles, which investigations included and covered the recti muscles only, and upon his studies are now based the fundamentals of this subject and out of his labors have come a nomenclature which is systematic and comprehensive.

In this field others collaborated and extended the investigations of muscle balance and imbalance until the peculiar functions of the obliques had been discovered and their anomalies also studied.

In this field, Savage was the real discoverer of the function of the obliques and he it was who gave to the science the most exact and dependable suggestions as to methods and procedure in determining their balance or imbalance and the treatment for same. It was necessary to have an instrument which would combine, in a compact form, all of the essential elements for bringing under test and observation each muscle in turn. This instrument must be based upon the laws of optics as applied to the eyes. Such an instrument was hard to conceive, and consequently the instruments first used fell short of the absolute requirements, though they marked a great advance in the science of phorometrics.

It might be observed in this connection, that in all probability one of the chief reasons why the real difficulties of this question were not sooner solved, lay in the fact that the observers were studying insufficiencies of certain muscles, rather than the excessive strength of those muscles which caused these seeming insufficiencies. This was the task to which Stevens applied his thought and energies, and the field which he opened up and cultivated to such a high degree has brought a wonderful harvest.

In this day and time we are now more concerned with the discovery of the lesser forms of muscle errors than with the grosser, and for their determination instruments of greater accuracy and range are required.

In 1888 Stevens, after much experience with the then existing methods of muscle testing, devised and presented for use and approval his binocular phorometer, which was the first of the kind. This instrument was a great advance in this field and really marked the beginning

of the evolution which has since developed the highest type of instrument of today, though this particular instrument can not be regarded as a safe and sound guide for the measurement of all muscle defects, as will be shown later in its description.

The underlying principle upon which the phorometer depends, is the detection of the ability of the musculature of any eye to fuse and hold images upon the macula which lie in the field of binocular fusion. For it is a well known fact that so long as the defect in strength is not greater than the limits of possible fusion, then the patient may be able to maintain binocular single vision, though with difficulty, especially so as the outer limits of the fusion field are approximated. Therefore it is most important that this field of binocular fusion should always be in mind and its limits or extent be understood.

The extent of this field is variously estimated by investigators, but many of them fail to stress it as an important factor in the detection of heterophorias, while in fact it is the important point to hold in mind. The result of investigations in this field vary very much, especially as to the temporal limits. The measurements are always made from the macula as a starting point.

The following are the findings of the investigators named:—*Howe 9.7°, Bannister 14.4°, Noyes 36° to 45°, Risley 25.4°, Savage 25°, Stevens 50°. These findings show great variations, for the temporal limits, but it is now generally accepted as 25°.

The nasal limits are approximately the same with all the above observers, namely 8°—, while the vertical limits are generally conceeded to be 2° to 3°.

The fusion field is then an area on the retina, extending from the macula 25° in the temporal direction; 8° in the nasal direction, each on the horizontal meridian passing through the macula, and 2 to 3° above and below the macula in a perpendicular direction, on the vertical meridian passing through the macula. A continuous line drawn through these points will include the fusion field, which is elliptical in outline and within this field impressions upon the retina can be more or less easily fused, depending on the distance in or out, up or down, along the horizontal or perpendicular meridians, upon or near which these impressions fall, and the determination of this effort to fuse objects which lie at any point in this fusion field outside the absolute point of perfect fusion, namely the macula, is the measure of the heterophoria present in any given case, and its kind will be measured by that prism, which with its base out or in, up or down,

* "*The muscles of the eye,*" Howe, Vol. I, p. 301.

will produce or bring about this fusion. Tonicity and fusion tests are only made in the cardinal directions. At this point it will be well to note the fact that when a prism is placed in front of one eye, the other being free to see and act alone without any obstruction, the image thrown upon the eye by the displaced ray due to the prism, sees the object in the distance in a new position, and that this displaced or false object is usually moving, while that seen by the unobstructed eye is still, and that the movements of the false object are toward fusion with the true; and that if the prism be one which displaces the false only to such a degree that the fusion faculty can prevail, then fusion will occur, but may not be maintained, hence the objects separate and fuse time and again, the false being that one which keeps up the movements. But if the displacement is greater, or the prism strong enough to prevent fusion, still the false object only moves. This point is often observed by the patient who calls attention to it. It is evident therefore that in order to measure the position of any image in or out, up or down, that is, away from or outside of the perfect fusion point, the macula, we must test each eye separately, for one eye must be at rest so as to produce or give a base line, from which we can measure the directions of the eye under test. In order to do this we must use a prism of such strength in front of one eye that it will throw the image on the retina outside of the fusion area in some given direction, thus suspending the fusion power in that eye in the line of direction in which the prism is placed, as well as in the plane at right angles to the displacement; the image now being without the fusion area, the fusion sense is temporarily abolished and the eye comes to rest (unless the patient looks from one object to the other), in a new position governed entirely by the strength of those muscles acting in a plane at right angles to the plane of displacement.

If there is muscle balance in the plane at right angles to that of the displaced image, the macula of that eye under test will remain in line, and there will only be diplopia in the direction of prism displacement, but if the opposing muscles are not balanced then the macula will swing or move out of line, and there will be a resulting phoria depending for its kind upon the stronger muscle of the pair under test. From this it is evident that one eye must be in a state of rest while the other eye is being tested, for we must have a standard or a fixed line, which joins the object in the distance and the image on the retina, and this can only be obtained when we allow one eye to view the object unobstructed.

If a prism is placed in front of each eye, the bases of these prisms being in opposite direction, and of sufficient strength to throw the

image on each retina outside of the fusion area, then neither eye fixes nor can fix the object in space, except it displace or rotate the retina so that the macula is brought under the point of impingement of the displaced ray or line of light, hence neither eye sees the object in its real position in space, consequently we have no fixed or base line, or line of direction, from which we can measure the displacement of either eye with certainty.

Again, in the determination of the strength of any given muscle, we must test that muscle alone. This can only be done when one eye is at rest and fixed upon the object or light, so as to establish a base line, or line joining the object in space and the macula in the eye; for otherwise we have a variable line or moveable base by which to measure the strength of either muscle of any given pair. Therefore when we desire to measure the strength or duction power, as well as the variations from the normal, or in other words determine the imbalance or the phorias or the duction strength, we must test each muscle in each eye, one at the time, the other eye being unobstructed by any prism or other device, which will cause it to make any effort whatever to change its position with relation to its primary position. In other words one eye must always be in the primary position, when testing the other, for variations from this position—in some rare cases, especially children who are timid or can not quite understand, or in the obtuse, it may be necessary to use a red flat glass, in order to act as a finder, which when it has served its purpose in locating the two objects, one colored, the other uncolored, can and should be discarded, if possible, and the test finished without its use, thus avoiding any disturbance to the fixing eye. It must be remembered and fully understood and conceded, that in order to obtain the best results in testing either the strength of the individual recti muscle or obtaining the phorias which may exist in any case, the object used for making these tests should be one which will always make upon the retina a small distinct image, easily seen, clearly defined and fully understood by the patient undergoing the test.

Such an object is a small light, the best perhaps is obtained by using an opaque chimney, as suggested by Landolt, with a small opening in one side, through which the light emitted will be constant and steady. The objection to the ordinary candle is that the flame flickers and moves from side to side with every passing breeze and at times becomes too much elongated.

A broad, flat, or a long slender, flame of an ordinary gas-jet should never be depended on, as the images produced by such flames are apt to invade the true fusion area, in one of the cardinal directions.

It might be well in this connection to state that only the displacing prism and the bright point of light should be used for final tests of vertical and lateral deviations, since Maddox rods and stenopaic lenses impress the retina within and across the fusion area, hence are only approximate.

The position and comfort of the patient are essential to proper testing. The patient should be in a comfortable position with head erect, the eyes in the primary position and fixed upon the light which should be at about twenty feet distant and in plane with the eyes. Excessive light should be excluded from the room and bright surfaces and objects should be out of line of the light, so as to prevent confusion. The ideal perhaps can be obtained when the light has for a background a dead-black, non-reflecting surface some 4 to 6 feet square, without any perpendicular or horizontal lines near the borders of the surface from which confusing reflections can originate.

These observations as to principles involved refer only to testing the recti muscles, but as the oblique muscles are also sometimes faulty as to balance it is necessary to consider them in our discussion of this question.

It would be manifestly out of place to discuss the point as to whether there is a normal turning in or out of the perpendicular axes or not, suffice it to say that if there is normal variation of the perpendicular axes from their true positions (parallelism with the median plane of the head), then there is also a normal phoria of some other kind, as referred to the recti muscles, which has not been defined nor indeed can be, hence we will not hold to any such dogma as tenable. If there be such a thing as heterophoria, which is recognized even to the smallest degree, due to imbalance of the recti muscles, then it must stand to reason based upon the physiological functions of the obliques as well as the recti, that if the recti must keep the visual axes parallel for distance or convergent upon the same point in the near without undue effort of any single muscle or pair of muscles, and that the vertical axes must be kept parallel with the median plane of the head and therefore with each other, then there can be no deviation of the vertical axes from the true vertical position, for in that event they would not be at right angles to the plane of the horizontal axes, hence could not and would not be true axes—nor primarily parallel with the vertical median plane of the head—and the obvious functions of the recti and the obliques, that of planing the horizontal and paralleling the vertical axes, would be defeated.

The testing of the balance of recti muscles depends on estimating their ability to fuse points of light upon the maculæ, which points

lie inside of the fusion area, and the measure of this ability of fusion is the measure of the individual effort of any muscle to produce and maintain this condition of fusion at such points—whether normal as in balanced or orthophoric conditions, or of imbalance or heterophoric conditions. Hence in such tests of the recti muscles we are dealing with fusion of points or efforts at fusion, alone. But, when we come to measure the balance or imbalance of the oblique muscles we are not dealing with, nor can we deal with, points, but are now dealing with lines of light which extend across the fusion area either in the perpendicular or horizontal directions; in other words we are dealing with meridional lines or planes, and consequently we must have a method of or a device for throwing upon the retina a continuous line of light, in order that the eye may be able to discover the lack of coincidence, of the linear impressions made upon the retina, with vertical or horizontal meridians.

For this purpose the Maddox rod is used, the best form being the multiple rod which throws a continuous line of light across the retina in the horizontal meridian, when placed vertically before the eye. As there must be a line of light in each eye, for the patient to be able to make a comparison of their relative positions in space, which is the reverse of that upon the retina, each eye must look through a rod, or multiple rod, at the same time, at the same light, hence this part of the test is binocular as to the instrument.

The first of the instruments used for this test was devised by Price, of Nashville, Tenn., in 1893, and demonstrated before the Ophthalmological Section of the A. M. A. at San Francisco, in 1894. It was a simple device used in the regular trial frame, consisting of a double Maddox prism, line of bases horizontal combined with a Maddox rod at right angles, in a single circular rim or cell made to fit the trial frame, and a Maddox rod fixed in a circular disc to fit in the other side of the trial frame. The eye before which was placed the double prism and rod saw two lines of light, horizontal and parallel, when looking at a candle, while that eye before which the single rod, axis vertical, was placed, saw a single line of light midway between the two lines of light seen by the other eye and parallel to them, when the obliques were orthophoric. While the pupillary distance could be properly adjusted by the trial frame, yet there was wanting the leveling device, which is absolutely essential, hence the instrument was imperfect though the principle was absolutely correct, and the foundation laid upon which the perfected instrument rests.

Brewer's instrument, which he called the torsiometer, was an improvement upon this.

A little later Savage devised and had perfected his cyclo-phorometer which meets all the indications both for testing cyclophorias and for making all cyclo-duction tests. Having discussed the principles upon which the instrument depends, it will be well to trace the instrument, as far as we may be able, from its beginning or simplest form, up to its present perfection.

It will be conceded that the first step in the discovery of the method of detecting and measuring both the deviations and the individual strength or duction power of muscles was taken when von Graefe held in his hand a prism of 15° base down before one eye of his patient and caused him to look at a vertical line with a dot at its center, held at the reading distance, thus causing vertical diplopia of the dot and line so that the patient now saw two dots on the single elongated line, one dot being above the other and on the same line now elongated, in which condition he recognized there was a balance of the lateral muscles, and in which he declared there was no "insufficiency of the interni;" or when the patient saw two dots on two lines, one dot and line being above the other and toward the opposite side from the prism, in which case he recognized there was an imbalance of the lateral muscles, which he declared was an "insufficiency of the interni"—which insufficiency was equal to that prism which held horizontally caused the fusion of the two lines, thus placing the two dots on one continuous line. If the inventive genius of von Graefe had only been prompted to make this test with a light in the distance, then indeed would ophthalmologists have had plain sailing, and this subject would have been eluciated long ago. It is perhaps unfortunate that the dictum of a great mind overshadows the initiative in those who immediately follow him. But while he failed to grasp the full significance of his discovery, he yet laid the foundation on which others have builded.

Gradually, the import of this fundamental step was improved upon, and as men got away from the idea of insufficiency of the internal recti, being the *sine qua non* in the investigations of the muscle question, there dawned a new era and the problem became one of discovering not insufficiency, but rather one of determining the *over strength* of individual muscles in any opposing pair. When asthenopia and insufficiency no longer dominated the minds of the investigators and the real issue came upon the horizon, then Stevens, the chief exponent of a new line of thought and investigation, with an inventive genius and a more comprehensive grasp of this problem, gave to the profession his phorometer. Then was inaugurated a real departure from

the beaten track and a marked advance in the scientific method of investigation.

In this connection it might be well to quote from an article in the *Medical Record* of May 5, 1888, by Stevens, in which he outlines his reasons for, and steps in, the invention of his phorometer.

"Experience had long since led me to observe that the method of determining the relative tendencies of the visual lines in respect to the horizontal plane by means of prisms held in the hand, or fixed in the ordinary trial frames, is an extremely imperfect one, adapted only to the rudest measurements. Two years ago I had constructed spectacle-frames in which were placed oblong quadrilateral prisms for the determination of hyperphoria. The form of these hyperphoria trial spectacles, by their rectilinear outline, enabled the examiner to determine their approximate relation to the horizontal plane.

"Further experience showed that the difficulty of adjusting the head of the patient was, in a considerable number of cases, attended with difficulty, and at the best, the adjustment of both head and glasses was, to a certain extent, inexact. This led to the introduction of the spirit-level as an indication of the position of the prism.

"It was found that the attachment of the level to the spectacle-frames presented little advantage, owing to the difficulty of maintaining a perfectly erect position of the head.

"I observed that if the prisms were placed upon an independent support and removed a few inches from the face, it mattered little if the head is held with perfect accuracy, and that in most cases it might be carried far over to one or the other side without altering the relations of the double images to each other or to the horizontal plane. The result of this observation was the phorometer which is here figured."

Stevens (*Motor Apparatus of the Eyes*, p. 273, 1906) describes his invention as follows:

The phorometer consists of a standard and adjustable arm and a slide with rotating prisms.

The standard is supported by a tripod and is extensible. At the upper extremity is an endless screw locking an arc by which motion is communicated to the arm. The arm, directly over the standard, is furnished with a spirit level. A slide containing two cells is so attached to the arm that it can be moved to any part of it. In each cell rotates a disc and each disc carries a prism of 5°. Each disc is finished with a border of cogs, and a small gear wheel placed between the two discs communicates movement from one disc to the other. A raised band around the border of each cell has a scale of degrees or

diopters increasing from the center each way from 0° to 8°, the numbers representing the refractive power of the prisms in diopters. The scale represents a greater degree of accuracy and uniformity in the refraction of prisms than is found in most of the trial cases in common use. By working the handle which is attached to one of the cells the two prisms are rotated in different directions; that is, if the edge of the right prism is caused to turn down, the edge of the left prism turns up, etc.

The letters, R. H., L. H. Es., and Ex. indicate the direction of the pointer when right or left hyperphoria, esophoria or exophoria is found.

Directions for using the phorometer. In using the phorometer the instrument is placed before the patient to be examined and always somewhat removed from the eyes. A distance of from four to six inches between the eyes and the slide is sufficient to permit of some freedom in respect to the movements of the head, and to insure against the natural inclination to neutralize the indications of heterophoria, which is always present when the instrument for testing is held too close to the eyes.

By raising or lowering the upper part of the standard the arm is brought to such a height that the patient, with the head as nearly as convenient in the primary position, can look through the glasses toward an object, preferably the flame of a candle, situated at a distance of twenty feet and at the height of the eyes.

The slide with the prisms will then be so placed that the side on which are the letters and the scales will be from the patient. The end of the slide marked R. H., and L. H. will then be before the right eye of the patient, and that marked Es. and Ex. will be before the left eye. Before making the examination the arm should be brought to a perfect level by means of the screw, as shown by the spirit level. If the examination is to be made with reference to the horizontal position of the images, the handle of the slide is brought to the upright position and the pointer to the 0° mark at the right side. The prisms are then absolutely level and their bases in, and homonymous diplopia is induced unless the eyes are able by abduction to overcome the prisms. This may be done in cases of rather high degree of exophoria, and it then becomes necessary to supplement the refractive power of the prisms by the addition of another prism. The slide of the prisms is provided with a little shelf or with a slot behind the prisms, and an extra prism, cut square and very exact as to its axis, may be slipped behind one of the rotating prisms. It is well to be provided with about three such square prisms, one each of 4°, of 6° and of 8°. These will serve for almost any emergency for one or two of these addi-

tional prisms will prevent the union of images. If they still unite we are dealing with a rather high degree of strabismus and not with heterophoria. Having thus induced homonymous diplopia, the next step is to ascertain whether the two images are absolutely in the same horizontal plane.

If the candle is in a part of the room otherwise only feebly lighted, it is an advantage and all casings, shelves, or other objects which may assist the patient in correcting his notions as to the horizontal should, as far as possible, be absent. The practice which some have adopted, of drawing horizontal and vertical lines behind the object (the candle), is thoroughly bad, since the impulse to correct a difference in height of the images, or a difference laterally becomes so much greater when such aids are present that the test is largely and often completely neutralized.

If it is found that one image is higher than the other the prisms are rotated until the images are level. By making the last part of the rotation quite slow a higher degree of correction may be possible than if the adjustment is quickly made.

The pointer now marks the amount of deviation of the images from the horizontal plane. If the pointer is above the 0° point, it indicates n° of *right hyperphoria,* but if below the 0° mark, n° of *left hyperphoria.*

It is well, after the test has been made, to throw the prisms out of position in order to verify the correctness of the result.

This test being made the lever is next brought down rotating the prisms, so that they are adjusted one with base down, the other with base up.

It is now ascertained whether the two images are in a vertical line. If the upper image is deflected to the right the pointer (on the left end of the slide) will be moved toward the letters Ex. that is, downward; if toward the left the pointer will move upward toward the letters Es. The figures on the margin will indicate the degree of exophoria or esophoria.

This description and method of using this instrument is given in full in order that it may be understood as its inventor has described it.

The Stevens phorometer while not designed nor used for that purpose by him, can be used for detecting the presence or absence of insufficiencies of the obliques, or cyclophoria.

In order to make this test the prisms are placed in the position for detecting the lateral (phorias) balance or orthophoria, that is, rotated so that the prism in the right cell is base up and that in the left cell

is base down. The patient should then look at a line about 2 inches long on a card, held at the reading distance. The line will now be doubled that seen in the right eye below, that seen in the left eye above, and the two lines will be parallel, in case there is oblique orthophoria, or balanced obliques. But if they are not parallel then there is loss of balance of the obliques or cyclophoria. If the lower line seen by the right eye tips or inclines downward toward the left, and if the upper line seen by the left eye tips or inclines downward to the right, then there is want of power in the superior obliques or plus cyclophoria.

Again if the lower line seen by the right eye tips or inclines downward toward the right, and the upper line seen by the left eye tips or inclines downward toward the left, then there is a want of power in the inferior obliques or minus cyclophoria. Thus while we can detect the presence and character, we can not determine the amount, of the cyclophoria, hence this instrument simply points the way and gives us a line on the further testing for defects of this class by some other instrument.

It will be observed in the use of the Stevens phorometer that each test whether for lateral or vertical deviations, does not meet the requirements now recognized as necessary, in that with it both eyes are tested at once hence there is no fixed or base line in the primary position from which to measure the deviations. This is due to the fact that the image in each eye is displaced by a prism outside of the fusion area of the retina, hence both eyes are out from under control of the guiding sensation of the retina and the fusion faculty, therefore neither eye, in the primary position, can fix the test object or light, consequently the tests are approximate and not absolute.

Attention should also be called to the fact that this instrument can not be used for testing the duction strength of the individual recti muscles, since both eyes are under test at the same time, whereas in any duction test of recti muscles, one eye must be free from any prism or any other device which causes the light seen by it to be deflected from the line of light in the primary position or plane.

We must necessarily then conclude, that the binocular phorometer is undesirable because it fails to meet the fundamental requirements as now understood, for the measurements of either the phorias or ductions.

Let it be said, however, to the credit of its inventor, that it was the first step in the evolution of the phorometer, and is the real foundation upon which those who came after him have builded. It may be said that it is far easier, now, to discover defects in instruments than it was to discover defects in muscle balance then.

The Wilson phorometer. This instrument consists of two cells upon an adjustable stand, with a spirit level attached for leveling, with a standard which can be attached to a table and raised and lowered to any convenient height according to the patient being examined. At the right side of the right cell is attached a circular disc with several openings, one being left open while in the others prisms are inserted, so that when this disc is rotated there can be brought concentrically before the right eye a prism of 10° base in or one of 10° base up, or one of 15° base out, or a double prism bases together.

In the left cell, or that in front of the left eye, is placed a Risley double rotating prism.

Method of using: The instrument is adjusted to the height of the patient, and leveled up so that the patient with head erect and comfortable and eyes looking in the primary position can see the light, which should be at twenty feet, the right eye seeing the light through the open aperture in the rotating disc, and the left seeing it through the rotating Risley prism with indicator at the zero mark.

If now, as is the common practice, we desire to test the lateral muscle balance, we revolve the disc so that the prism of 10° base up is brought concentrically before the right eye. This at once produces vertical diplopia by throwing the object for the right down. The patient is then asked if the two lights seen are in the same vertical line. If the response is in the affirmative then there is orthophoria for the lateral muscles, and the slightest movement of this rotary prism will cause the upper image to pass or move to the right or left away from the vertical according as we rotate the base out or in from the zero point on the scale of the rotating prism.

If the response is in the negative, then we ask if the upper light is to the left or right of the vertical line. If it should be to the left of the vertical line, then the patient has esophoria, or homonymous diplopia; if to the right, then the patient has exophoria or crossed diplopia.

The character of the phoria present being disclosed, we then rotate the prism, in esophoria, so that the base is turned outward until the light is brought into the vertical line, or the lights are one directly over the other, and the degree or degrees necessary to produce this verticality is the determination of the number of degrees of the esophoria.

If exophoria is the condition presenting we then rotate the prism in the reverse direction until the lights are brought into the vertical position when the number of degrees indicated on the rotating prism determines the degrees of exophoria present.

Having discovered the presence or absence of orthophoria, esophoria, or exophoria, and having determined the amount of esophoria or exophoria in any given case, we can now apply the test for the vertical phorias, as follows:

Revolve the disc, until the prism of 10° with base in or toward the nose is brought in front of the right eye. This will produce lateral diplopia; the false object, seen by the right eye, should be in the same plane as the true, seen by the left eye, and to the right, in which event there is vertical orthophoria. But if the false object should be higher, then there is right cataphoria or turning downward of that eye, and the rotating prism should be turned so as to place the prism base down in front of the left, until the true object for that eye is brought up to a level with the false object, and the number of degrees indicated will measure the cataphoria present. If, however, the false object is lower than the true, then there is hyperphoria, or turning upward of eye, and the rotating prism should be turned so as to place the prism base up in front of the left eye until the true object is brought down to a level of the false object, and the number of degrees indicated will measure the hyperphoria present.

Again if the double Maddox prism be rotated in front of the right and the patient now observe the light, there will be two lights seen by the right eye and one by the left. If orthophoria exist for both sets or all recti muscles the three objects would be in the same vertical line, and the true or that seen by the left eye, would be midway between the upper and lower objects, seen by the right eye. But if the true object is to the left of the vertical line joining the upper and lower objects and midway between them, there is esophoria or homonymous diplopia. If, however, the true object is seen nearer the upper false object there is cataphoria or downward turning of the left eye, while if nearer the lower false object, then there is hyperphoria or upward turning of the left eye.

The rotating of the Risley prism until the objects are in the vertical line in the esophoric or exophoric condition will approximate the amount of either present, while in the event of the true object being either above or below the point midway between the false objects the rotating prism can be turned until the true object is brought down or up to the proper position and the approximate degrees of vertical variation determined. It might be well to observe at this place, that this test will at once disclose both the lateral and vertical phorias and give us a line or working basis upon which to base further investigations of the muscle state.

For instance if the false objects and the true object are not in the

vertical, nor the true object midway between the false objects, then this at once suggests the combination of phorias with which we have to deal. Example: If the true object seen by the left eye is to the left of the vertical line of the false objects and at the same time is lower than the point midway between the false objects, then we have a combination of esophoria and hyperphoria in the left eye or a condition of hyper-esophoria at once revealed. If the true object be to the right of the vertical line and nearer the bottom light, then we have a hyper-exophoria, or a combination of exophoria and hyperphoria. Then too if the same lateral deviations are found and the phoria should show the object above and to the left, or to the right, then we would have the cataphoric combinations, or, as sometimes called, the hypophoric conditions or hypo-esophoria or hypo-exophoria.

In addition to these tests this instrument can be used for testing the duction power of vertical recti and also the external rectus in full, which as a rule in orthophoria does not exceed 8° to 10°, and the internal rectus up to 10°. To make these tests we proceed as follows: To test the duction power of the superior and inferior recti muscles, we rotate the disc before the right eye until we have the open space or aperture presenting, and the rotary prism before the left eye in the neutral position with the axes of the prisms horizontal. Now rotating the prism before the left eye so that the bases are moved up or down the indicator will show in degrees the point at which the doubling takes place, thus determining the amount of duction power of the superior or inferior rectus, which should be about 3° for normal.

The balance or imbalance of the obliques can also be detected by the use of this instrument. To make these tests we proceed as follows: The open space in the disc is brought before the right eye, and the rotary prism, in the neutral position, before the left, axis horizontal, and the instrument carefully leveled. Then having the patient observe a horizontal line on a card in the near, or a white line upon a black board in the distance, the rotary prism is now revolved, as if testing for super-or subduction, until the line is doubled. If now these lines are parallel in both positions, there is an orthophoric condition of the obliques. If, however, the lines are not parallel, then there is cyclophoria. In this case the true object will remain horizontal and the false object is the one which dips downward, either to the right or the left. If it should dip down to the right, it would show insufficiency of the superior oblique of the left, or plus cyclophoria. If it should dip down to the left, it would show insufficiency of the inferior oblique of the left, or minus cyclophoria.

This instrument cannot be used for testing the strength or lifting power of the obliques.

It is unfortunate that an instrument of so many possibilities is yet not to be depended upon on account of the fact that the fundamental principle upon which these various tests are made, and must depend, is wanting in its conception, namely the testing of each eye separately, or that, throughout all these tests, one eye shall always be free of interference in order to establish a base line to reckon from. This base line is the line which joins the object in the distance with the true image on the macula of the eye not under test, while that eye is in the primary position, and the line joining the image on the macula and the light in the distance are in the primary horizontal plane. Hence while this instrument is one of a wide range in detecting the presence of all forms of heterophoria its usefulness for determining the amounts or degrees of such anomalies cannot be depended on, being only approximate.

The Maddox near vision phorometer. This instrument, constructed upon the suggestions of E. E. Maddox, "is designed for the rapid and accurate diagnosis of muscular imbalances."

"It will be seen . . . that it takes the form of a hand instrument to be held by the patient. It has two eye pieces of neutralizing colors. The horizontal consists of a green scale with figures above. This is intersected at right angles by a red dotted vertical line. The amount of any existing esophoria or exophoria can be immediately measured, being indicated by the dioptric divisions on the scale. By turning the scale to the vertical, hyperphoria can be at once measured. If the patient is asked to place the dotted line in the vertical position, a scale at the back will show the amount of any existing cyclophoria."

The description as quoted in above paragraph, is sufficient to show that this instrument cannot be relied upon for any more than an indicator of possible muscle imbalance for it carries all of the possible "donts" in any device for accurate determinations of muscle errors.

First it is a binocular instrument, second it tests the muscles in the near only, which we know is not reliable, except for near measurement of the lateral muscles.

The discussion up to this point, has been based upon those instruments which have been in common use, and which, up to the time when it was conclusively demonstrated and practically accepted by all who have given this subject serious study and consideration, that

the binocular phorometer is not a scientific and dependable instrument for the final determination of muscle errors.

This then brings us to the question as to the correct principle of construction of the phorometer. Several points are fundamental and must be observed in every examination for testing muscle balance or imbalance in any and every case.

The position of the patient and the test light, a small point, or a white dot upon a broad smooth, dead-black back-ground, must be so related that there is no undue strain upon any muscle or pair or combination of muscles, under normal conditions.

The head erect, in easy position, eyes in the primary position and the test object at the point of intersection of the horizontal and perpendicular planes extended at about twenty (20) feet distant.

These conditions being met, the determination of muscle balance or imbalance resolves into determining whether or not three given points are in the same plane. These points are the macula, in each eye, and the distant object. Two of these points are movable or adjustable, and one is fixed. The movable or adjustable points, the maculæ, become fixed points in the same palne, whenever the image of the light or distant point falls and remains stationary upon each of them, without undue effort on the part of any one or more muscles of the adjusting apparatus to maintain this equilibrium.

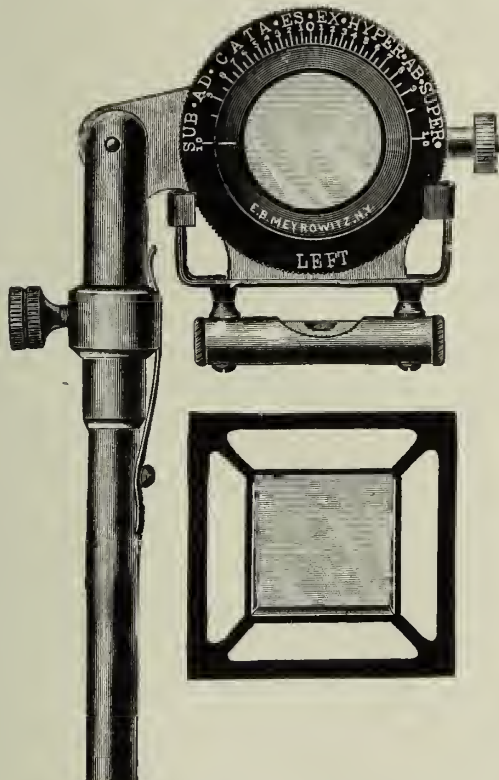
Now as the distant object, the light, one of these three points, is in a fixed position, in a given plane, then one of the movable points, or the image of the fixed distant test object upon one of the maculæ, must be and must remain in a fixed position in this same horizontal plane (the primary plane), with a straight line joining these two points, in order that we may have a fixed or base line from or by which we can measure any deviations of the other movable or adjustable point or macula, from this plane. It is evident therefore, that one eye, with its movable or adjustable point or macula, must view the distant test and fixed object, unobstructed by any prism or device whatsoever which would cause any deviation of the straight line which joins and must join its macula and the distant test light or dot, that is, the object and the image must be joined by a straight line lying in the horizontal plane.

In other words the true image, the control, must always be on the macula, and the false image must always be thrown outside of the fusion area for binocular single vision, in the eye being tested.

These conditions, which are absolute and imperative, can only be met when one eye alone is tested, the other being the control, which

establishes the base line from which we reckon and record the deviations, if such there be, in the eye under test.

Hence we conclude that in the final test, to determine the actual conditions of balance or imbalance and the amount of the specific phoria in any given case, resort must be had to that kind of instrument by which each eye separately is brought under test, and which



Savage's Monocular Phorometer.

is also capable of testing each muscle independently, both as to its verting and ducting power. Such an instrument is the monocular phorometer.

Savage's monocular phorometer. The first to recognize the absolute necessity of testing for errors of balance in the recti muscles with a monocular instrument was Savage, and his reasons for such a conclusion were based upon the principles involved in this question; and he then evolved and had made according to his suggestions such an instrument as would meet all the indications and requirements for testing

each eye and each rectus muscle separately. This instrument consists of a rotary prism, of the Risley type, mounted in a substantial receptacle, with spirit level attached, and cells or slots on both sides, that is, front and back for holding the displacing prisms. This receptacle is mounted upon an upright rod with movable joint with screw and spring mechanism by which it can be leveled. This piece of the mechanism is mounted on a horizontal arm, attached to an upright extension rod, which can be raised or lowered to any reasonable height by sliding in a metal tube which stands upon a substantial base, or can be attached to a wall bracket. The rotary prism is accurately marked in degrees up to 10—and lettered for each eye—and is reversible so that it can be used in front of each eye. The displacing prisms are mounted in square cells, so that accurate positions at 90° or 180° can be easily, quickly and surely obtained. The prisms used for displacing the light are 6° for the vertical and 10° for the horizontal displacements.

Method of using the Savage phorometer. With the patient in a comfortable position, head erect, eyes in the primary position and the test object, a point of light or a white dot on a dead-black back-ground at twenty feet, and in same horizontal plane with the eyes, the rotary prism is placed before the right eye of patient and properly leveled, with the axis of the rotary prism vertical and the patient instructed to look at the light. If now we desire to test the lateral balance or imbalance or phoria, we place the 6° prism, base up, in the slot behind the rotary prism or next to the eye of the patient, thus producing vertical diplopia.

The displaced or false object is now seen by the patient below the true object, the false being seen by the right eye and the true seen by the left eye. The false object is now below the horizontal plane, the fusion faculty is suspended, and the false object will assume that position dependent upon the balance or imbalance of the lateral muscles of the right eye. The patient is instructed to look at the true object all the while. Now if the muscles which control the lateral tendencies of this eye are properly balanced, then the false object will be directly under the true object in the left eye—and there is orthophoria. If now while the patient watches the true object, the prism be rotated in either direction the false object will move to the right or left of the perpendicular line passing through the true object.

If, however, the false object be not directly under the true, but out to the right or the left of the perpendicular line passing through the true object, then the tendency to imbalance or the lateral heterophoria of that eye is manifest. If it be to the right of the perpendicular

line, it is esophoria, and the prism is now rotated toward Es. marking upon the face of the rotary prism scale, until the false object is brought directly under and in line with the true object, when the number of degrees indicated will determine the esophoric tendency in the right eye, or the esophoria present. If the false object be to the left of the true, it is then exophoria, and the prism is now rotated toward the Ex. marking upon the prism scale until the false is brought directly under the true object, when the number of degrees indicated on the scale will determine the exophoric tendency of the right eye or the exophoria present.

For testing for these lateral phorias, in the near, a white card, upon which is a black dot, is held at the reading distance and the tests as indicated above are repeated.

In testing the vertical muscles the rotary prism is turned so that its axis is horizontal, the rotating screw being vertical. In order to produce diplopia in the horizontal direction, so that the balance, imbalance or any tendency thereto, may be made manifest, we place the 10° prism in the slot next to the eye of the patient, with its base in, which displaces the image beyond the binocular fusion area inward. This produces diplopia in the horizontal plane. The patient is now instructed to observe the true object seen by the left eye, which is unobstructed, and this is to the left of the false object, seen by the right eye, which is to the right. Now if the muscles which control the vertical tendencies of the eye under test, the right eye, are properly balanced, then the false object will be directly to the right in the same horizontal plane and there will be vertical orthophoria. If while the patient watches the true object, the prism be rotated either up or down, the false object will move above or below the horizontal line passing through the true object, always coming back to the horizontal line when the zero point on the prism scale is reached.

If, however, the false object be not on the horizontal line passing through the true, but down below or up above the horizontal line passing through the true object, then the tendency to imbalance, or the vertical heterophoria of that eye, is manifest. If the false object be below, then there is right hyperphoria, and the prism is now rotated toward the Hyper marking upon the face of the rotary prism scale, until the false object is brought up to and directly in line with the true, and the number of degrees indicated on the scale will determine the amount of hyperphoria in the right eye.

Again if the false object should be above, then there is right cataphoria, or left hyperphoria, and the prism is now rotated toward the Cata marking on the face of the prism scale, until the false object is

brought down to, and directly in line with the true, and the number of degrees indicated on the scale will determine the amount of cataphoria in the right, or the hyperphoria in the left, eye.

The tests for vertical phorias, in the near, are made with the card and black dot held at the reading distance, by repeating those tests for distance just outlined above. In order to discover the balance, imbalance, orthophoria or heterophoria of the muscles of the left eye, the rotary prism is placed before the left eye, the right eye being unobstructed, and now becoming the fixing or control eye, and the procedures above outlined are followed in order to determine, measure and compare the findings with those just recorded present in the right eye.

It might be well to state at this point that the findings in each test, bear a rather close relation to each other, as far as the tests for the lateral phorias are concerned; that is, esophoria in the right is generally accompanied by esophoria in the left, of or near the same degree, but if the esophoria of the one exceed or is higher than the esophoria of the other, then that eye in which there is the greater amount of esophoria is in all probability more defective in its focus, especially so in cases of hypermetropia.

In case of the vertical phorias, while the amounts are approximate in degrees, yet we find that hyperphoria of the one is usually accompanied by a cataphoria of the other, and in rare instances only do we find either hyperphoria or cataphoria present or presenting in both eyes. This pehaps is accounted for by the fact that in the plane in which are located the three points which should always, for perfect balance, lie in this plane, the horizontal, yet two of these points are movable or adjustable, namely the maculæ of the retinæ, and these points rotate, as it were, around the line of intersection of the horizontal and perpendicular planes, while the fixed point, in the triangular plane, is at the point of convergence of the lines drawn from the maculæ to this point. Now the fixed point in distance remains fixed, but if either of the movable points is depressed below or elevated above this movable base line of this triangular plane, then there is a corresponding complementary elevation above or depression below this plane to maintain their mutual relations as to position but not as to function.

The tests for the recti muscles, having been made and recorded, we can now proceed to determine the balance or imbalance of the oblique muscles or the cyclophoria, if any be present in any given case. This can be accomplished with this same instrument by removing the displacing prism from the cell or slot, and using the rotary prism alone.

With the instrument in adjustment for testing for vertical phorias or orthophoria the displacing lens is removed and the patient is now instructed to look at a horizontal white line upon a dead-black blackboard at twenty feet.

The rotary prism is now turned down until the line is doubled, the false image is seen by the eye before which the rotary prism is placed; if these lines are parallel, then there is orthophoria of the obliques. The movement of the rotary prism is reversed, and continued until the false object is above the true, and if parallel there is balance of the obliques. If there is want of parallelism, between the false and the true object, then there is imbalance of the obliques or cyclophoria, the kind being indicated by the tilting or dipping of the false object.

If the rotary prism be before the right eye and the displaced or false object dips downward to the left then there is imbalance of the obliques; the right superior oblique being insufficient in its action allows the right eye to tort outward, thus causing a dipping of the image of the line in the opposite direction or downward to the opposite side, which condition is known as plus cyclophoria. Should the line dip downward and on the corresponding side then there is insufficient action of the inferior oblique or minus cyclophoria. The presence and kind of cyclophoria alone can thus be determined, but not measured. Having tested the right eye for any oblique imbalance, or phoria, the rotary prism can be placed before the left and the test repeated. As a general rule it may be stated that the phorias of the obliques are similar and approximately the same in each eye.

In order to determine the amounts or degrees of cyclophoria present in any case, we must resort to the use of the cyclophorometer, the description and use of which will be given a little later.

Duction:—After having noted, tested and determined the heterophoric condition of each eye, as regards its recti muscles, then with this instrument we can and should also test and determine the duction power of each of these in turn.

To test the duction power of the vertical muscles, the rotary prism is adjusted and leveled so that its axis is horizontal and the revolving screw is vertical. With the rotary prism thus adjusted before the right eye we turn the screw revolving the prisms so that the indicator points toward the marking Sub., on the face of the prism scale, and note the number of degrees on the scale at which the distant point of light separates into two lights. This will give in degrees the subduction or the duction strength of the inferior rectus muscle, which under normal conditions is 2° to 3°.

Bringing the indicator back to 0° and then revolving it in the

direction of the Super marking upon the scale, and noting the point at which the light separates into two, we at once read the number of degrees of superduction or the duction strength of the superior rectus muscle, which under normal conditions is 2° to 3°.

This test should be repeated several times and slowly in order to gain the best results and most accurate estimate of duction power, for a sudden displacement of the image will cause a too sudden movement of the object, hence a premature doubling; while a slow even movement of the prism will encourage the eye to maintain fusion up to its possible limits of duction. Sometimes moving the indicator only a half to a degree at the time with a slight pause will give the best results.

To test and determine the duction power of the lateral muscles, that is, the abduction and the adduction, the rotary prism is brought into the neutral state, with axis now vertical, before the right eye. By reason of the fact that the rotary prism alone will only record 10° of duction, it is well to test the abduction first, as it generally falls within this limit; hence we turn the rotating screw so that the indicator moves in the direction of the Ab. marking on the scale, and note the point at which the lateral doubling or diplopia takes place, the number of degrees can be at once seen, read and noted. Abduction usually is 6° to 8°, if it is less than 6° it may be regarded as subnormal and if more than 8°, super-normal.

The rotary prism is now turned back to its vertical neutral position, and as the normal adduction usually exceeds the 10° limits of this prism, it is necessary to supplement it with one, and in some cases two, of the supernumerary prisms. It is well to begin this test with the 15° prism placed in the slot next to the patient's eye, with its base out or toward the temple. If perchance this prism should be too strong, and cause a doubling of the objective light, then the rotary prism can be turned in the direction of the Ab. marking on the scale until the objects are fused and the degrees of abduction indicated should be noted, which if less than 5°, must be subtracted from the 15°, which will indicate the abduction, which in such case is subnormal. If no doubling of the light occurs then the rotary prism must be turned in the direction of the Ad. marking upon the scale, and continued up to 10°, provided no doubling occurs before that point is reached. If doubling occurs when the 10° point on the scale is reached, it indicates adduction of $10° + 15° = 25°$ or the average normal. If doubling does not occur when the 10° point on the scale is reached, then it indicates that adduction is 25°+. In this event we place in the slot in front of the rotary prism the 5° or 10°, supernumerary prism, base out,

which in addition to the 15° prism already in the slot behind the rotary prism, will measure the adduction up to 30° to 35°, in other words we have 15° in the supernumerary behind, plus the 10° of the rotary prism, plus the 5° or 10° supernumerary prism, in front of the rotary prism or 30° to 35° adduction, which is usually within the ordinary limits of the internus and marks the limits of this instrument.

The abduction and adduction of the right having been noted, the rotary prism can be reversed and the same test repeated for the left eye.

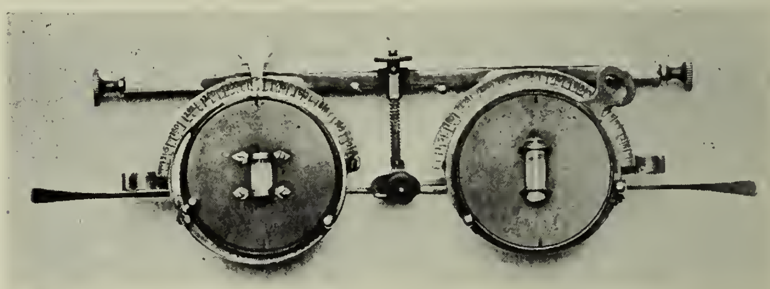
It will be observed that in all of these duction tests only one eye is tested at the time, and each muscle separately, while the other eye remains fixed by direct vision upon the test object, thus giving us a fixed or base line joining two fixed points, the object in the distance and image on the macula in the fixing eye. The eye under test will move slowly, holding its macula upon the distant object, so that object and image are superimposed, until the deflecting prism has moved the object outside the fusion area, when it can no longer maintain binocular single vision, then the doubling occurs and the measure of strength is the amount of its duction resistance.

At this point it might be well to impress and emphasize this fact, namely, that any method of testing the orthophorias of the recti muscles in which any lens, prism or maddox rod is used, which will displace, confuse or spread out over the fusion area or highly color the ray of light from the distant object which should fall upon the macula, as a single point, of the fixing or unobstructed eye, is faulty and unreliable and should be discarded. Again, in the eye under test the image of the distant object should always be a point of light, clear and distinct, best displaced outside the fusion area and not spread out over or drawn through it as a single line, or confused by a lens or colored glass, except as a finder, to be discarded when the patient has discovered what you intend to be seen, so that the real test can be finished.

Having thus tested the phoric tendency and determined the orthophoria or heterophoria of each eye, as well as the duction strength of each of the recti-muscles, we now come to consider the question of testing the balance, imbalance or insufficiency of the obliques, which for the sake of conforming to the terminology now in use, and generally recognized as the best, was called cyclophoria by me in 1893—at which time I also devised a combination of double prism and maddox rods for discovering and testing the presence or absence of this condition. The apparatus consisted of the following: A double prism bases horizontal and a maddox rod at right angles to base line of prism.

The rod was fixed in an opaque disc with a small opening at its center, across which opening, behind the disc, at right angles to the axis of the rod, ran the base line of the prisms. This combination, in a cell which was of the usual size of a trial lens, was placed in one of the cells of an ordinary trial frame, and in the other cell was placed a simple maddox rod fixed in an opaque disc, with a small central opening through which to view the distant light.

Looking at the light through the combination of double prism and rod with the bases of prisms horizontal and axis of rod vertical, the patient saw two horizontal lines of light, which lines were parallel; then adjusting the single rod vertically in front of the other eye, so the patient could see the streak-light through the single rod, the patient



Price's Phorometer.

In the right cell of the trial frame is the opaque disc with double prisms behind and the rod in front. In the left cell is the single rod fixed in the opaque disc. These can be changed from right to left; thus each eye can be tested separately.

saw a single horizontal line of light with that eye, which single line was between the two horizontal lines and in case of orthophoria of the obliques it was parallel with them. This device was named the *cyclophorometer,* and was demonstrated before the Section of Ophthalmology at the A. M. A. at the San Francisco meeting in 1894. This instrument, the first cyclophorometer to be devised, was imperfect in that it was not provided with a spirit-level for adjusting the double prism and rod, and the single rod in the horizontal line.

Notwithstanding its imperfections it could yet be used to obtain approximate results as to the quantity, while the character of the cyclophoria could be determined with as much certainty as by any of the more highly perfected instruments. Hence, in order to perpetuate its memory, as well as establish its identity, I herewith present a cut showing its parts and features.

The Torsiometer. Sometime after this Baxter, of Mass., and Brewer,

of Conn., devised instruments using the same idea, but having the leveling attachment for adjusting the horizontal position of the prisms and rods.

Some question of priority having arisen between these gentlemen, which discussion appeared in the *Ophthalmic Record,* I called attention to my discovery and instrument through the *Ophthalmic Record,* July 1898, and Brewer was generous enough to write that journal and accord to me the credit for having first suggested and used the Maddox rod for testing the position of retinal meridians. The instrument of Brewer was called the *torsiometer.*

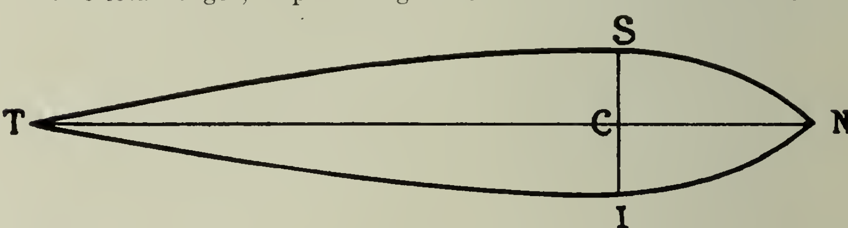
In testing for cyclophoria we are testing the relations of meridians and not points, consequently we must produce in each eye the image of a line of light along a meridian, usually the horizontal of each eye. This meridional streak or line of light is produced in one eye by a Maddox rod in front of that eye, when the distant light is viewed through the rod, thus causing a linear image upon the retina, which is in the horizontal meridian when the axis of the rod or rods is vertical. Now if the rod, single or multiple, be in front of one eye, with axis vertical, and the other eye is unobstructed, the patient when viewing the distant test-light, will see the line of light produced by the rod, as a bright linear object, and also the distinct point of light seen by the unobstructed eye. This point of light may be on the line at its center, above, below, to the right or left of the center of the horizontal linear object, but the relation which any line drawn through the single point bears or would bear to linear object cannot be determined, hence we must convert the point of light into a line of light, which is accomplished by a rod interposed between that eye and the distant light, its axis being vertical, which produces the horizontal linear object necessary for comparison with that of the fellow eye.

But as each of these linear objects is in the same meridian, and each within the fusion area of its own eye, the fusion faculty would overcome any slight variation, insufficiency or cyclophoria, and the patient would see only one horizontal line, hence we must displace the one or the other outside the fusion area. In my original instrument this was done by the combination of double prism and rod before one eye, causing a double displacement, and the rod alone before the other. In later instruments this is accomplished by a single prism, base up or down behind one of the rods. From these facts and considerations we discover that in the testing for cyclophoria we are compelled to compare meridians and not points and as we can only do this when we produce linear meridional images in each eye at the same time, we are therefore resorting to a binocular instrument.

Another important and fundamental fact in the construction of any cyclophorometer with reference to the position of the axes of the rods, multiple or single, is that the linear image, produced upon the retina should always lie in that meridian which affords the greatest length of image within the limits of the fusion area. Because the greater the number of nerve fibres bearing impulses to the centers of control, the fusion faculty, the greater the resistance to disturbances of equilibrium along that line over which this control is maintained. Upon this very fact is based the ability of every patient to overcome, or compensate for a much higher degree of esophoria than exophoria, without discomfort, the ratio being about three to one.

We recognize this factor in testing the superior and inferior recti muscles by causing the displacement of the image inward, with a prism of 10°, since this prism displaces the image, as a rule, beyond the fusion area, and hence beyond the control of the fusion faculty.

The total length, in prism degrees of the horizontal diameter of the



Outline of the Fusion Area of each Retina.

fusion area is temporal 24° plus nasal 8°=32°, while the total length of the vertical diameter of the fusion area in degrees, is up 3° plus down 3° = 6°.

A graphic representation of this problem may be given in the following diagram, which is an irregular elliptical figure representing the outline of the fusion area of each retina. Its major axis is composed of two sections, a temporal C. T. and a nasal C. N.; its minor axis of two sections C. S. above and C. I. below.

If C., the center of the macula, be the rotation point, as well as the center of the fusion area; C. T. = 24 units or degrees, the temporal section or long arm; C. N. = 8 units or degrees, the nasal section, or short arm; C. S. = 3 units or degrees, the superior section or arm, of minor axis; C. I. = 3 units or degrees, the inferior section or arm of minor axis; then if we, for the sake of illustration, suppose that each axis is a lever resting on C. as a fulcrum and stable in its equilibrium, then it will at once appear that in order to maintain equilibrium of these forces, it would require three times as great a force applied at

N. as at T., and the same amount of force applied at S. as at I, according to the mechanical law of the action of levers, to keep up or maintain this equilibrium. Now this is exactly what occurs in the action of the recti muscles, for the internus acts as if applied to the short arm of the lever C. N. and the externus acts as if applied to the long C. T., consequently the duction strength or power of the internal rectus is relatively three times that of the externus.

In the case of superior and inferior recti muscles, the superior acting on the lever arm C. S. and an inferior acting on C. I. which are equal in length, are maintained in equilibrium by the same amount of power applied at the respective points S. and I., hence these muscles, as a general rule, have the same amount of duction power, or strength.

Now, therefore, if we produce a linear image in each eye, by a rod or rods, the equilibrium will be more stable on that meridian which offers the greatest number of units of fusion force under the influence of the fusion faculty; hence we conclude that the linear image or streak of light produced by the rods should lie in the horizontal plane, with its 32 units of fusion force in each eye, as against the 6 units of fusion force in the vertical.

Upon these considerations is based the assertion that the single or multiple rods in any cyclophorometer should be so placed that their axes are vertical, thus producing the horizontal streak upon the long arm or axis of the fusion area.

The peculiar function of the obliques in normal conditions of refraction is to keep the vertical axes of the eyes parallel with the median plane of the head; which means that the horizontal retinal meridians, each bisecting its own fusion area, shall be in a common plane, which plane is that of the primary isogonal circle.

A *cyclo-phorometer*, to be a complete instrument, must not only be able to determine the presence or absence of cyclophoria, but must also be so constructed as to measure the amount, and in addition measure the cyclo-duction of the individual oblique muscles. Such an instrument has been devised by Savage, based upon the suggestions contained in the original instrument of Price, and I herewith give his description in full.

Savage cyclo-phorometer. "The cyclo-phorometer, . . . made for use with the monocular-phorometer stand, or the Wilson phorometer holder, consists of a base on which rests two graduated cells, in each of which is to be placed a triple Maddox rod with axis vertical. Behind each of these cells is a rectangular cell for a displacing prism. There is an arrangement by means of which the pupillary distance ean be easily regulated so that the one streak of

light may be brought directly under the other. There is beneath the base of the instrument a spirit level for regulating the adjustment of the instrument. On each disc containing the rods is marked below by a line continuous with the axis of the central rod. The rods placed vertically, with a prism of 5° base up behind one of them, will show two horizontal lines of light when a candle flame is looked at. The lower one will be seen by the eye before which is the combination rod-and-prism. The lines should be parallel and their ends even. The latter can be regulated by turning the screw that controls the pupillary distance. The slightest movement of either disc will cause a loss of parallelism of the streaks of light. If not parallel, there is a want of orthophoria of the obliques, the kind and quantity of the error being shown by the rotation of either disc.

"This instrument is designed for detecting and measuring the insufficiency of the obliques, or the cyclophoria, whether plus or minus, and also for determining the duction power of each oblique, but not cyclo-version, as the eyes cannot voluntarily rotate around the visual axes."

In this connection it might be well to call attention to certain names or terms for designating this peculiar function of the eyes, which have been introduced into the terminology of muscle defects or deficiencies.

In 1893, in order to perpetuate the classical terminology introduced by Stevens, I suggested and used the term *cyclophoria*. If the tendency of the vertical axes of the eyes was outward or from the median plane of the head it was called plus cyclophoria, if inward or toward the median plane of the head it was called minus cyclophoria. Maddox used the terms "plus torsion" and "minus torsion," and Stevens "plus declination" and "minus declination;" all of which terms have the same meaning, and it seems a little strange that Stevens did not accept the terminology which coincided with his own original classical, and much used terms.

Method of using the cyclo-phorometer. The patient must be in position for testing the recti muscles, with the test object or light, a candle or small gas jet in the distance, about twenty feet. The cyclo-phorometer, is then adjusted in its proper position in the phorometer stand, brought to a perfect level and the index of each triple rod brought to the zero mark on the scale, and the patient then instructed to observe the light.

Instead of a point or small blaze he discovers a streak or line of light in the horizontal plane. This is the image of the fused line or streak of light produced by the rods, seen by both eyes combined. It is interesting. Now place a prism of 5° base up in the slot behind

one of the rods, this at once displaces the object for that eye below the horizontal plane and consequently he sees two lines or streaks of light, the false below, the true above. In order to prevent any confusion in discovering their relative positions and answering surely, certainly and quickly, any questions, we now place a red glass in the slot behind the other eye, and the patient at once sees a red streak above and a yellow streak below. If their ends are not even, the regulating screw, which causes the cells to approach or separate, can be turned in one or the other direction until the ends of the lines are evened up.

If the eyes are perfectly balanced, as to their obliques, the streaks are parallel, and there is orthophoria of the obliques. We will presume that the 5° prism is before the left eye and the red glass before the right eye, then the yellow streak is below and the red streak above.

In the event there is loss of parallelism of the streaks, it will be noted that the red streak, fixed by the right eye, is horizontal and the yellow streak seen by the left eye dips down toward or inclines to the right. There is a convergence of the two streaks at the left hand ends, showing there is plus cyclophoria. But if there is convergence of the streaks at the right hand ends there is minus cyclophoria.

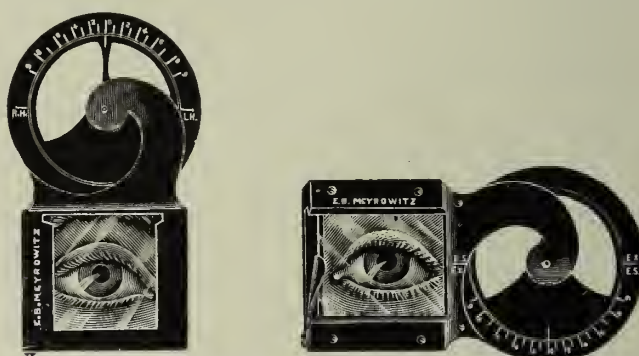
Thus we discover the presence or absence of cyclophoria, and the next step is to measure it. As the measure of the degree of cyclophoria is determined by the amount of the rotation of the rod in front of the eye under test necessary to bring the inclined streak of light into the horizontal position, we turn or rotate the disc containing the rods behind which the displacing prism stands, until the streak is in the horizontal position, which will at once establish parallelism of the streaks, and the degree of rotation will determine the amount of cyclophoria.

If when horizontal parallelism has been produced and the index of the rotated prism stands in the lower nasal or the upper temporal arc, then there is plus cyclophoria, and the quantity or amount in degrees can be read upon the scale. If it is found necessary to rotate the rod so that the index of the rotated rod rests at a point in the lower temporal or upper nasal arc, then there is minus cyclophoria, and the quantity or amount in degrees is indicated on the scale, whether above or below, at which the index rests.

Having determined the character or kind, as well as the quantity or amount, of the cyclophoria present in any case, we can also, with this same instrument, determine the intrinsic strength or duction power—the cyclo-duction of each of the oblique muscles. To make the cyclo-duction tests we remove the displacing prism from behind the rod, the patient will then see but one streak, since the fusion faculty has re-

asserted its function and the two streaks occupy the same relative position in each fusion area.

Now the test for cyclo-duction is determining how far you can rotate the rods in either direction before the one streak is doubled into two streaks. If we desire to test the superior oblique of either eye, we turn or rotate the rod in front of that eye into the lower temporal or upper nasal arc, and stop the instant the doubling occurs, this is minus cyclo-duction. For the inferior obliques we turn or rotate the rod into the lower nasal or upper temporal arc, and stop the instant the doubling occurs, this is plus cyclo-duction. The amount of cycloduction in either case will be indicated by the position of the index on the graduated arc of the cell. Normal cyclo-duction varies considerably, being from 7° to 14° for a single oblique. The combined cyclo-



The Wells Handy Phorometer.

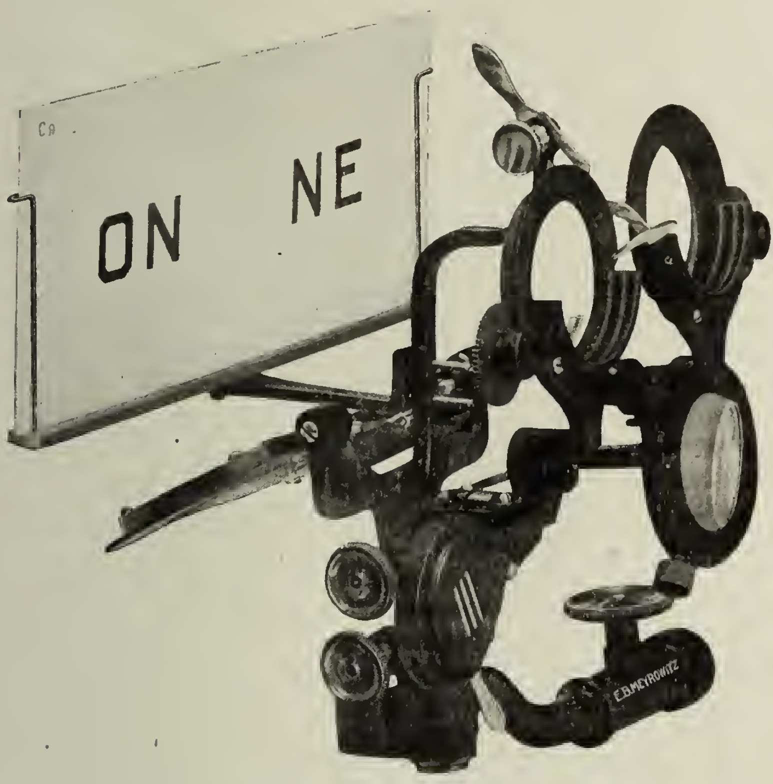
duction of both superior obliques can be obtained by turning or rotating both rods simultaneously into lower temporal or upper nasal arcs, and that of the inferior obliques by turning or rotating both rods simultaneously into the lower nasal or upper temporal arc. The result of this test shows the combined cyclo-duction of either pair of obliques to be from 12° to 22°.

From the foregoing, it is evident that the monocular phorometer of Savage, with its adjunct the cyclo-phorometer, is capable of making every test commonly made or resorted to for testing either the recti or the oblique muscles in every phase.

Wells handy phorometer. The instrument, as its name suggests, is a "handy" or vest-pocket edition, so to speak, of the more elaborate instruments used for testing the various phorias of the recti muscles. As an out-of-office or dispensary instrument for approximating and demonstrating purposes it is unique, as it will indicate the condition

which, if requiring further study, can be gone over by a more complete or trustworthy instrument in the office. One point which commends it is that it is monocular. The description and method of using it by its designer and maker is herewith given:

"This little instrument consists of a 10 diopter prism, mounted in a frame having attached to it a weighted disc which indicates the level position on the principle of a plumb-bob. This obviates the necessity



Wells' Stereoscopic Attachment for Phoro Optometer.

of a spirit level. The graduation from 1 to 9 prism diopters is worked out on the same principle as the Stevens phorometer. The instrument is graduated on one side to show Ex. and Es. and on the other R. H. and L. H.

"In testing L. H. and R. H. the disk is held above.

"The instrument measures ¼ inch by 1¾ inches by 3 inches and weighs but a few ounces. When the prism is exactly vertical or horizontal the index points to zero. If the images are not in line, the

instrument is twisted until alignment is secured, when the amount of the error is shown on the index."

The improved Wells instrument as now put upon the market resulted from the suggestions of J. H. Claiborne, of New York, which obviate the necessity of changing the prism in measuring the vertical and horizontal muscles.

Bartel's phorometer, for near vision. Bartel's phorometer consists of a tangent scale calculated for near vision (25 and 50 cm.). The zero point is perforated to show light from a candle flame behind. The test is made with a Maddox rod. The to-and-fro lateral movements of the light streak are ascribed to the slight variations in the accommodation.

No experience in the use of this instrument should, perhaps, bar one from any expression of opinion as to its practical use. But the fact that the instrument is designed for near use, and that it is based upon the use of the Maddox rod as the medium for producing the change in the light, may be regarded as sufficient ground for entering a word of caution, since both of these fundamental factors or features of construction produce unreliable results, except in indicating the kind of phorias which may be present. Near tests, except for comparison with those made in the distance, give but limited information, and the Maddox rod cannot be depended on for accurate results except for the oblique muscles.

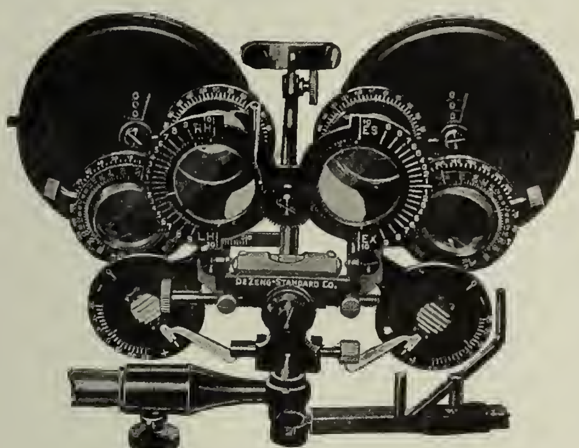
The last word, up to the present, in phorometer construction, is that instrument which combines all of the suggestions and ideas of proven worth, which have been developed by the preliminary steps heretofore taken by those ophthalmologists who have from time to time put forth their best effort in this broad, complex and fertile field, and to the genius of the optical instrument makers, who have devoted so much of time, skill and energy to the perfecting of a single compact and complete instrument, which embodies within itself all the essential potential possibilities of all the individual efforts of the past. The chief exponents, or representatives, in this field of endeavor, whose names stand out most prominently are Risley, Stevens, Savage, Maddox, Wilson, Baxter, Wells and Price, each of whom has devised one or more of the basic elements or features of the present almost perfected phorometer.

The instrument referred to is that known as the phoro-optometer of De Zeng, or Meyrowitz, each of which combines all of the essentials of the more primitive instruments, heretofore devised and suggested for testing muscle balance or imbalance, plus the optometer.

In discussing the use of this particular form of instrument, I shall not consider the optometer, for that is another question not contemplated in this article, but shall confine myself to the phorometer and its uses alone.

Again, as these instruments are quite similar in their combinations of units of proven value it would add too much to the length of this section to describe each in detail of construction, and discuss the uses and possibilities of each. Being more familiar with the De Zeng instrument, I shall therefore use it as the basis of my discussion.

De Zeng's phoro-optometer, and the phorometer-trial frame. In the above forms we have presented the type of the most complete instruments yet made. In considering the phorometer, the phoro-optometer



Phoro-Optometer, DeZeng.

will not be discussed further than those features which are included in the phorometer-trial frame and attention will be directed specifically to the phorometer feature alone.

In this instrument are combined all the essential elements for measuring all the various forms of muscle balance or imbalance as well as ductions of recti and oblique muscles. It is compact and adjustable, provided with spirit level, interpupillary control, head rest and near point test. For use it is mounted according to choice of operator, upon a wall bracket, floor stand or fixture to be attached to chair.

Viewing the latest instrument from before backward it is found to combine the following: a Stevens phorometer, a pair of Maddox multiple rods, mounted in graduated supports; a pair of Risley double rotary prisms of 30 diopters power, one mounted on each side. These elements, namely the Maddox rods, and the Risley prisms are so

attached that each can be used separately and when not in use can be turned down to the right or the left out of the line of vision. Behind the rotary prism on either side, is a three-cell, gear-driven, trial-lens holder, which may also serve as a supplemental prism holder, under certain conditions, when necessary. (The Stevens phorometer has been eliminated from the latest model.)

As we are familiar with the construction of these various parts and their uses, they will not be discussed in detail.

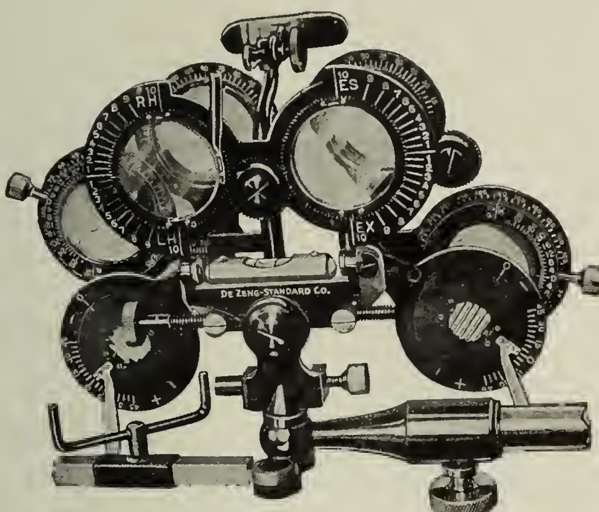
DeZeng Dark Room Lantern for Use with Phorometer.

Of course the same instructions and precautions as to the proper adjustment of the instrument in all directions; the position of the patient, as to the instrument and the test light, each and all apply with as much force in the use of this, as any other, form of phorometer, in order to obtain full and accurate results, and should always be followed as a routine before beginning any test for the sake of comfort to patient and information to the examiner.

At a glance the instrument suggests to the mind of the average operator the beginning of the muscle testing by the use of the Stevens phorometer. This being a binocular instrument, it must be borne in

mind that such tests are only suggestive and approximate, consequently must be regarded as such. The peculiar features of and facts concerning these tests have already been fully discussed under the head of the Stevens phorometer and the reader is referred to that section.

However, it might be well to call attention to the fact that in his description and instructions as to use of this part of this instrument, the manufacturer has, in a recent publication, made use of the Stevens phorometer and the Maddox multiple rod as the basis for making the binocular test of the recti muscles. This procedure will do where you desire only to *get a line*, so to speak, on the general condition of muscle balance, but it is especially undesirable as a real test, for no real test



DeZeng Phorometer Trial Frame.

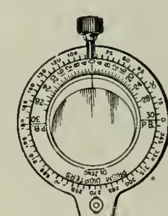
of recti muscles should be made with a Maddox rod, for reasons given heretofore, namely, that in dealing with recti muscle balance you are dealing only with the position of a point of light in space or distance and the image of that point upon the retina outside of the fusion area. If these precautions are kept in mind, this method of approximating conditions may be resorted to, but it would be just as well to use the instrument as Stevens used it, that is, with the point of light alone. These very points and cautions are stressed by the author of the admirable little book of the manufacturer, for the guidance of those who use the instrument.

To use the instrument as a monocular, we proceed as follows: As the instrument has no independent simple prism which can be placed

in front of the eye to be tested, the Risley rotating prism is brought into position in front of, say, the right eye, with the zero graduation horizontal, then move the indicator upward on the prism scale 6° or 8°, which equals a prism of as many degrees, base up in front of the right eye, which will displace the test light downward outside the fusion area, causing vertical diplopia. If now the false object seen by the right eye and the true object seen by the left eye stand in the same vertical line, there is lateral balance of the recti muscles of that eye, hence lateral orthophoria of the right eye.

But if the displaced, lower object is seen to the right side of the vertical line passing through the true object, then there is manifest lateral heterophoria of the right eye and being homonymous it is esophoria. Should the displaced object be to the left of the perpendicular line, then there is crossed diplopia or exophoria.

To determine the amount of either phoria, the Risley prism is brought up into position in front of the left eye, with the zero gradua-



DeZeng Universal Double Rotary Prism Unit. Similar to the Crete or Risley Prism.

tion vertical, and the indicator is rotated outward or inward on the prism scale to that point, which causes the two objects to lie in the same perpendicular line. The number of degrees on the scale at which the indicator rests will show the amount of esophoria or exophoria. The condition of the lateral muscles of the right eye having been determined we resort to the test of the vertical muscles of same eye.

The Risley prism is placed before the right eye, with the zero graduation vertical, and the indicator is now turned inward on the prism scale to 12°, which is virtually placing a prism of as many degrees, base in, before the right eye, which throws the image outside of the fusion area, hence produces lateral diplopia. The false object seen by the right eye and the true seen by the left eye, if seen in the same horizontal plane, indicates vertical orthophoria or balance. But should the object seen by the right eye lie below the horizontal plane there is right hyperphoria, while if it should lie above, there is right cataphoria.

In either event the amount of hyperphoria or cataphoria in the right eye can be easily measured by bringing the rotating prism in front of

the left eye, with its zero graduation horizontal and rotating the indicator upwards or downward to such a point on the prism scale as will cause the two objects, the false and the true, to assume a position in the same horizontal plane. The reading in degrees will show the amount of vertical phoria. The rotating prism is so constructed that rotations of the indicator up measure the hyperphoria and rotations down measure the cataphoria of the other eye, in this case the right eye.

The muscle balance, as to the recti of the right eye, having been obtained and recorded, the left eye can be tested in the same manner as the right, and the results also recorded. To the close observer of phorometer practice it will at once appear that there is a fundamental defect in this instrument which can be and should be remedied by the maker—since this is not a true monocular instrument in the uses to which it has just been put, for this reason. In testing the right eye the false object produced by the use of the rotating prism, fixed in either the position to produce the vertical or lateral diplopia, demands that the true object in the opposite eye must be moved by the rotating prism either up or down, in or out, in order to induce the necessary correction of position for any muscular deviation, whereas this should not be the case, for the true object should always remain undisturbed in its position in order to maintain the true base line, heretofore referred to as an essential condition, hence we are forced to the conclusion that it is not a true monocular instrument in its present plan of construction.

This imperfection can be easily overcome in two ways; first by using a single prism of 6° or 8° accurately marked as to axis to be placed base up in the rotating cylinder cell of the trial frame attachment, so that its axis shall be exactly vertical or at 90°, to produce vertical diplopia, in making tests for lateral deviations or phorias; and a single prism of 10° to 12°, accurately marked as to axis, to be placed in the rotating cylinder cell of the trial frame attachment, so that its axis shall be exactly horizontal, or at 180°, to produce the lateral diplopia in making the tests for vertical deviations or phorias: or, second, by having two independent prisms one of 6°, base up and one of 10° base in, so placed and attached behind the rotating prisms that either can swing into position behind the rotating prism to produce the vertical or horizontal diplopia as required in making these tests. When such an arrangement or attachment is made, the instrument will then become a monocular phorometer for either eye, or a double monocular phorometer, thus eliminating the cross reading, as now required.

Duction tests of the interni, externi, superior and inferior recti muscles are easily, readily and accurately made with this instrument.

The duction tests for the muscles of the right eye are made in the following manner. The double rotary prism is brought into position in front of the right eye, with the zero mark vertical or neutral in position as to prism action, the left eye being unobstructed, and the patient instructed to watch the distant light and as soon as two lights are seen to say "two." In this position we can determine either adduction or abduction. To determine the adduction, or strength, of the internal rectus, we rotate the indicator outward, which is equivalent to successively placing prisms of increasing strength, with their bases outward, before that eye, until the single light doubles into two lights in the same horizontal plane, when rotation should stop, and the amount noted. This rotation of the prism should be done slowly, and repeated several times, as this will develop the highest duction power of which the muscle is capable. The usual duction strength or power of the internus is 24° to 25°. If it should be higher than this the prism will measure it up to 30°, without the use of an additional prism. If the adduction should go above this, then prisms of 5° or 10° can be held in front of the rotary prism, base out and axis horizontal until the full power is estimated. This, however, is unusual.

When the adduction has been determined, measured and recorded, the rotary prism is returned to its position, with zero mark vertical and prism neutral.

To determine the abduction, or strength of the external rectus, we rotate the indicator inward, which is equivalent to successively placing prisms of increasing strength, with their bases in, before that eye, until the single light is doubled into two lights, in the same horizontal plane, when the rotation should stop and the amount be noted. This test should be repeated slowly, several times, in order to develop the highest abduction, which is usually 8° or about one third of the adduction. Abduction may vary as does the adduction, but usually not so much. The amount should be recorded for comparison and study.

In order to test the superduction, that is, the power of the superior rectus and the subduction, or power of the inferior rectus, of the right eye, we make use of the same rotary prism before the right eye, with its zero mark in the horizontal line.

With the rotary prism in this position rotating the indicator downward, is equivalent to successively placing prisms of increasing strength, bases down, before the right eye, until the single light is seen to double into two lights in the same vertical plane. As soon as the doubling or diplopia occurs, the rotation should stop. This should be repeated slowly, and the highest prismatic strength should be recorded

as the superduction or duction power of the superior rectus muscle, which is usually 2° to 3°, though in some it may be more, in others less.

With the rotary prism returned to the horizontal neutral position, we now rotate the indicator upward, which is equivalent to successively placing prisms of increasing strength bases up, before the right, until vertical diplopia is produced. This should be repeated for reasons heretofore stated, and the indicated amount recorded. This is the measure of the subduction or duction power of the inferior rectus, and is usually 2° to 3°, more or less.

The duction power of each of the recti muscles of the right eye having been made and recorded, the rotating prism in front of the right eye is turned down out of the way, and that on the left side of the instrument is placed in position in front of the left eye, and all the tests are repeated for the muscles, individually, of the left eye, and the results recorded for comparison with those obtained in testing the right eye.

Testing for cyclophoria, or imbalance of the obliques, is quite similar to the method pursued in the use of the cyclo-phorometer of Savage. It has been pointed out that the test for cyclophoria is a binocular test, since we are now dealing with lines of light along meridians and not points. In order to produce these lines or streaks of light in each eye, for comparison, we bring into position the Maddox rods, one in front of each eye, with their axes vertical, so that each will produce a horizontal streak of light upon the retina. The patient now looking at the distant light, sees it, not as a point, but as a single streak of light in the horizontal.

If now the rotary prism is brought into position before the right eye with its zero graduation in the horizontal, the combination being neutral, the patient still sees but one streak of light; now rotate the prism so that the indicator moves upward to 6° or 8° on the prism scale, which is the same as placing a prism of as many degrees base up in front of the right eye. The patient now sees two streaks of light, which should be horizontal, with ends even and parallel. If the ends are not even, the screw for adjusting the interpupillary distance can be turned until this is overcome. If now the lines are parallel, then there is orthophoria of the obliques. Should the streaks not be parallel it will be noted that the lower streak, the one displaced outside the fusion area, is the one which dips or inclines while that one within the fusion area is horizontal. The displaced streak or linear image is in the right eye, before which is the prism with base up, and the horizontal streak or linear image is in the left eye.

If the dipping is toward the left, there is insufficiency of the right superior oblique, or plus cyclophoria, but if the dipping is to the right, then there is insufficiency of the right inferior oblique, or minus cyclophoria. Rotating the rod into the temporal arc until the dipping streak comes to the horizontal position will produce parallelism of the two streaks and the amount of the plus cyclophoria will be noted on the graduated scale of the rod. Rotating the rod into the nasal arc until the dipping streak comes to the horizontal will produce parallelism of the two streaks and the amount of the minus cyclophoria will be noted on the graduated scale of the rod. These tests are repeated for the left eye in order to determine the state of balance of its obliques.

The result of these tests for cyclophoria should be recorded, as they are important factors in placing the axes of cylinders, especially in cases of oblique astigmatism. As the duction power of the obliques is quite essential to a full understanding of their action in any given case, we should test and note the cycloduction of each pair. In order to make the tests for cycloduction, we cause the patient to view the light through the rods alone, the displacing prisms having been turned down and out of the way, so that each eye sees the light, now converted into a streak, by the rods, which will appear as one streak, the fusion faculty now being in control. Both rods should be made of white glass.

The axes of the rods should be perpendicular, so that the fused streak will be horizontal. As heretofore stated, the cycloduction test is to determine how far either rod can be rotated in either direction before the single fused streak is doubled into two streaks.

To test the superior oblique of either eye, we now slowly rotate the indicator from the zero mark inward into the nasal arc until the single streak is doubled into two streaks, whereupon the indicator will show upon the scale the amount of minus cycloduction, either right or left according to the rod which has been rotated.

To test the inferior oblique of either eye, the rods again having their axes perpendicular, the indicator being at zero on the scale, and the fused streak being horizontal, we slowly rotate the indicator from the zero mark outward into the temporal arc until the single streak is doubled into two streaks, when the indicator will show upon the scale the amount of plus cycloduction, either right or left according to the rod which has been rotated.

Normal cycloduction is 7° to 14° for each single oblique.

The combined cycloduction for both superior obliques is obtained by rotating both rods simultaneously into the nasal arcs, while that for the inferior obliques is obtained by rotating both rods simul-

taneously into the temporal arcs. The combined cycloduction for either pair of obliques ranges from 12° to 22°.—(G. H. P.) See, also, **Muscles, Ocular.**

Phoroscope. A fixed trial-frame for eye-testing, with a headrest which may be fastened to the table or the wall.

Phorotone. An instrument for exercising the muscles of the eye.

Phose. Any subjective sensation, as of light or color.

Phosgene. Light producing. *Phosgene gas* is a name for carbonyl chloride.

Phosgenic. Photogenic; light-producing.

Phosis. The production of a phose.

Phosphaina. (L.) Phosphene.

Phosphatic index in ophthalmology. J. Clemensha (*N. Y. Medical Journal,* March 23, 1912) explains that the phosphatic index is determined after a prolonged series of observations on the urine of many hundreds of different persons in a normal state of health. The urine, after much experiment, used to determine the phosphatic index was the second sample or that passed about ten o'clock in the morning, of a normal specific gravity, reaction, amount, total solids, etc.

Using a test tube holding 30 c.c., 20 c.c. of urine was placed within and 8 c.c. of Tyson's alkaline solution added. The mixture should change to a milky character at once, varying in degree of density according to the amount of phosphates present. The test tube should be placed aside for ten minutes. The phosphates will sink according to their specific gravity; if normal and well formed, they sink rapidly, whereas if small, light, and immature they fall slowly, even at times remaining stationary, causing a general turbidity throughout the whole fluid. If normal, in ten minutes they sink to the bottom, occupying a space that can be filled by 5 c.c. of fluid. This is the average of several hundred patients in a perfect condition of health, and is known as the phosphatic index. If the phosphates occupy a larger space than 5 c.c. normal index, it is known as a plus index, if less, a minus index.

The size and weight of the precipitate are important factors. It may fall to a normal index, but in appearance the sediment is fluffy, light in color, and easily moved about on agitation of the test tube. When normal, they settle like fine sand, and agitation of the tube does not disturb them. In the former condition, or where they will not sink or only partially so, being fluffy, they must be considered as deficient.

Phosphates precipitated by Tyson's solution appear fern-shaped, but the crystals vary in size. The usual size is about five-eighths of an inch in diameter, but according to the condition of the nervous system, they may be only one-eighth of an inch relatively when viewed

with one-eighth inch objective. The size of the crystals is quite important. In those cases where there is an excessive amount, they may appear very small, and these are the cases which show increased nervous excitement. They are small where there has been a continued drain on the residual reserve of nuclein and lecithin.

The apparatus used for taking the phosphatic index is known as the Dowd phosphatometer, and the theory as described is that observed and worked out by J. Henry Dowd, and for the phosphatic index he deserves whatever credit there may be due. He concludes as follows:—

The phosphatic index measures the amount of nervous energy present in the organism.

A high index will note a condition of irritation or a want of adjustment of the nerve cells.

A low index shows a lack of nutrition of the nervous organism, a using up of the reserve, and a condition below par.

A high index calls for nerve sedatives, valerian, or bromide of gold and arsenic.

A low index calls for food, eggs, etc., and the administration of phosphorus and strychnine.

The urine should be that passed about ten a. m., the second in the morning.

The crystals should be examined for size and quality.

In any functional disorder or one accompanied by organic lesions, the phosphatic index is of the greatest value as a guide to treatment.

In all cases look to assimilation and correct any intestinal putrefaction shown by an excess of indican.

Phosphaturia. Not only has asthenopia of various kinds and degree been attributed to this condition, but it has been accused of producing retino-choroidal and other fundus changes. The most important and most probable alteration is, however, morbid changes in the lens—*phosphaturic cataract.* Teissier, of Lyons, discovered in twenty patients suffering from diabetic phosphaturia three with cataract. H. Dor in 1877 investigated this subject and found the normal amount of phosphates excreted in normal urine to be about 2.50 grams per litre; 3.75 grams during the 24 hours. During observations extending over two years he found seven cataractous patients whose lenticular opacities could only be attributed to their phosphaturia.

Phosphene. A name originating with Serres d'Uzes, to indicate the sensation of light produced by mechanical irritation of the eye as a whole or of the retina.

Phosphene, Accommodation. The streak of light surrounding the visual field seen in the dark after accommodative efforts.

Phosphene, Czermak's. This subjective sensation is the appearance of a bright border around the visual field during a sudden relaxation of accommodation in the dark, a phenomenon said to be caused by dragging on the retina about the ora serrata.

Phosphene, Pressure. A phosphene produced in the retina by moderate pressure on the eyeball.

Phosphorescence. Strictly speaking, the term is applied to the phenomenon, exhibited by certain bodies, of remaining luminous in the dark for some time after being exposed to a strong light. Certain preparations, such as calcium sulphide, radium (see **Luminous paint**), indurated limestone, etc., possess this property in a very high degree. With the great majority of phosphorescent bodies, however, the duration of the phenomenon is very short, rarely more than a small fraction of a second. Becquerel, who studied this phenomenon with great care, invented a very ingenious instrument for the purpose, called a *phosphoroscope*. With the help of this instrument almost all bodies are found to be phosphorescent. When phosphorescence is continuous, we have the phenomenon observed by Brewster and Herschel in quinine and certain crystals of *fluorescence*. The green coloring matter of leaves, and the common canary glass are bodies which exhibit this phenomenon very well. See, also, **Insolation.**

Luminosity due to putrefaction or to disease. The fact that many organic substances (especially fish) become luminous when decaying has long been known. It is only quite recently that the discovery of luminous bacilli has rendered possible any general explanation of these facts.

Luminosity of healthy living organisms. In the *vegetable* kingdom the instances of the occurrence of this property are but few, and the majority of these belong to the algæ and fungi, the bacilli or bacteria above mentioned being referable to the former.

In the *animal* world there is not one of the large groups, up to and including the fishes, which does not afford some good examples of this phenomenon. Among the Protozoa the small spheroidal *Nociluca milaris* is perhaps the most widely-spread instance of this property. It is the usual cause of the phosphorescence of the sea. Of the Cœlenterata, the common hydroid colony *Obelia geniculata,* often growing upon the fronds of Laminaria (sea-tangle), is a familiar instance. Numerous Medusæ (jelly-fishes) must be added to the list. Most Pennatulidæ (sea-pens) furnish instances of the possession of this property; while Alcyonarians, Siphonophores, and Ctenophores also supply contributions to the list.

A few species of Ophiuroids (brittle stars) and the deep-sea asteroid

Odinia constitute the only known instances of luminosity among the Echinodermata, but the worms furnish a larger array. Among the marine Chætopoda the power resides in the dorsal scales (elytra) of the Polydoidæ, in the tentacles, dorsal tubercles, etc., of Chætopterus, and the bunch of cephalic tentacles of Polycirrus. Many Crustacea are luminous under normal conditions, and more particularly the Schizopoda. Definite organs (photosphæria) are here present for the production of light.

There still remain for consideration the phosphorescent *insects.* Luminous beetles appertain to the families Lampyridæ and Elateridæ. The glow-worm (Lampyris spendidula) and the Italian firefly (Luciola italica) are good examples of the former, and have been often described. In both cases the organs, which are situated in the posterior segments of the abdomen, consist of two layers, of which the dorsal contains large quantities of uric acid salts, and the ventral clear cells, which are arranged in cylindrical lobules.

Among fish the phenomenon is frequent, the organs concerned in the production of light being often highly specialized in the deep-sea forms. (*Standard Encyclopedia.*)

Phosphoridrosis. See **Eyelids, Phosphoridrosis of the,** p. 5020, Vol. VII of this *Encyclopedia.*

Phosphorograph. An impression obtained by throwing a luminous image on a phosphorescent surface.

Phosphoroscope. (a) An instrument for measuring the duration of evanescent phosphorescence. (b) A scientific toy for exhibiting effects of phosphorescence.

Phosphorus, Ocular relations of. One of the metalloids or non-metallic elements, this substance affords an excellent example of allotropy; that is to say, it may be made to occur under different forms presenting different properties. Ordinary phosphorus and the red variety are the only important forms. We shall speak of them as phosphorus and red phosphorus respectively.

Phosphorus at ordinary temperatures is an almost colorless or faintly-yellow solid substance of sp. gr. 1.836, having the glistening appearance and the consistence of wax, and evolving a disagreeable alliaceous odor. It fuses at 42.2° C. (111.5° F.) into a colorless fluid; and, if the air be excluded, it boils at 290° C. (554° F.) and is converted into a colorless vapor of sp. gr. 4.35 (air = 1.00). If, however, it be heated to about 60° C. (140° F.) in the air it catches fire, burns with a brilliant white flame, and is converted into phosphoric anhydride; and indeed it is so inflammable that it will catch fire at ordinary temperatures by mere friction. It is insoluble in water, slightly soluble in

ether, but dissolves freely in benzol, in the fixed and essential oils, and in bisulphide of carbon. Phosphorus shines in the dark from the slow combustion which it undergoes; and hence its name, from the Greek words *phos,* "light," and *phoros,* "bearing." Taken internally, phosphorus is a very powerful irritant poison; and it is the active ingredient of some of the preparations employed for the destruction of vermin. Its fumes give rise to a peculiar form of necrosis of the jaw, jaundice and to fatty degeneration of the kidney, which used to be common amongst the makers of lucifer matches.

Red phosphorus is prepared from the ordinary variety by heating the latter in a closed iron vessel to a temperature of 240° C. (464° F.). It is a compact solid substance of a dark-red color, and with a metallic luster. It differs much in its properties from common phosphorus, being devoid of odor, does not shine in the dark, undergoes no change when exposed to the air even for years, and cannot be set on fire by moderate friction or percussion. Moreover, it is insoluble in all the solvents of common phosphorus, and is not poisonous. It bears heating to nearly 260° C. (500° F.) without taking fire, and has a specific gravity of 2.16. It is used in the manufacture of matches. (*Standard Encyclopedia*).

Retinal changes have, according to Jeffries, been noticed in both acute and chronic phosphorus poisoning. De Schweinitz speaks of retinal hemorrhages followed by fatty degeneration of the tissues, and an ophthalmoscopic picture recalling that of albuminuric retinitis.

Schwarz (*Encyklopädie der Augenheilk.*, p. 669) remarks that the usual toxic icterus shows early in the sclera, that fatty degeneration of the retinal vessels is not uncommon, accompanied by the same process in the nuclear layer of the retina. It is the former of these lesions that is responsible for the retinal hemorrhages.

Photalgia. Pain caused by intensity of light.

Photantitypimeter. An actinometer.

Photaugiaphobia. This is a name coined by Ernest Clarke (*Med. Press and Circular*, August 4th, 1915) to express a shrinking from the glare of light, such as is particularly the case in albinos. It is a much more prevalent symptom than is generally thought. An extreme instance of the harm that may be done by glare is to be found in the so-called "eclipse blindness" or "electric retinitis," where changes can actually be seen with the ophthalmoscope in the retina (and choroid). Among the other conditions set up in the eye by glare may be mentioned cyclitis and traumatic conjunctivitis, sometimes accompanied by erosions of the cornea. The author explains how the one-time treatment of photaugiaphobia by smoked or colored glasses is likely to be replaced by

the glasses devised by Sir William Crookes. Two kinds of this glass are upon the market, namely, "A" and "B." Crookes' "A" cuts off 27 per cent. of the heat rays, practically all the ultra-violet rays, and transmits 99 per cent. of the light. In Clarke's opinion, "it is just the ideal glass for photaugiaphobia," and Clarke strongly recommends it, not only in the alleviation of glare, but also in the correction of myopia. On the other hand, Crookes' "B" is especially indicated when very great glare or heat is encountered.

Clarke's very practical communication concludes with an enumeration of the details that deserve attention in a case of photaugiaphobia —for example, the protection of the eyes against glare from above in the bright weather, the choice of house illuminants, the decoration of rooms, and the position of the bed in dormitories, and of the desks in class-rooms.

Phote. The unit of photochemic energy.

Photerythrous. Sensitive to the red rays of the spectrum: said of a form of color-blindness in which green is not clearly recognized.

Photesthesis. Sensitiveness to light.

Photic. Pertaining to light.

Photics. Optics.

Photism. A visual image; a sensation of color produced by a sensation of hearing, taste, smell, or touch. See **Chromatic audition,** p. 2186, Vol. III of this *Encyclopedia.*

Photo-actinic. Giving off both luminous and actinic rays.

Photobiotic. Living in the light only.

Photocampsis. Refraction of light.

Photocauterization. Cauterization by radio-active means, such as radium, X-rays, etc.

Photochemical. Of, or pertaining to, the chemical action of light.

Photochemistry is a comparatively new science occupying itself with the relation between radiant and chemical energy. These have only recently been made a subject of systematic research.

Among the manifestations of photochemical energy are such well-known effects of sunlight as formation of green colors in plants, self-purification of rivers and lakes, destruction of micro-organisms, bleaching of different colored substances, etc. The fact that hydrogen peroxide (H_2O_2) is formed by the action of light on water in the presence of oxygen seems to partly account for many of these phenomena.

A great many substances are now known to be sensitive to light, e. g., chemical combination of chlorin and hydrogen ($H_2 + Cl_2 = 2HCl$), formation of hydrochloric acid in chlorin water under de-

velopment of oxygen ($2H_2O + 2Cl_2 = 4HCl + O_2$) transformation of ordinary phosphorus to the red modification, reduction of ferric salts to ferrous salts, and the reduction of "latent" alteration of silver salts on which photography is based.

The chemical activity of any ray depends on its wavelength, and it may be exhausted when the ray is passed through substances on which it acts. According to Eder all light rays, from the infra-red to the ultra-violet, are capable of some photo-chemical activity, but only such rays as are absorbed by the substance in question have any effect on it. It may be stated as a general rule that the rays from the violet end of the spectrum, including the ultra-violet ones, have the most powerful chemical effect on colorless substances, though exceptions to this rule are known (a solution of sulphureted hydrogen in water, for instance, is decomposed more quickly in red than in violet light). Colored substances are, generally speaking, acted upon most energetically by the rays corresponding to their own color. The sensibility of a photographic emulsion towards red or yellow light may, therefore, be increased by dyeing the emulsion slightly red or yellow (orthochromatic plates). (*Standard Encyclopedia.*)

For the photochemistry of the retina, see **Physiological optics**, and **Comparative ophthalmology**. Von Kries (*Ophthalmology*, IX, p. 291, 1913) has also written on this subject.

Photochromatic. Of, pertaining to, or produced by, photochromy.

Photochrome. A photographic print in colors.

Photochromography. The art of reproducing on a printing-press photographic images in several colors.

Photochromolithograph. A chromolithograph in the production of which photographic processes have been used.

Photochromoscope. An optical device in which by means of a triple photograph it is possible to reproduce the light and shade and colors of nature.

Photochromotype. A photographic picture in colors typographically reproduced.

Photochromy. The art of photography in colors.

Photochronograph. (a) An instrument for making photochronographic pictures. (b) A picture so made.

Photochronography. The process of taking, at given intervals of time, a number of instantaneous photographs of a moving, or otherwise changing, object.

Photodermatism. Sensitiveness to light in epithelial cells.

Photodrome. An apparatus for regulating flashes of light so as to make a rotating wheel or figured disc appear either stationary or as if rotating at a different rate or in the opposite direction.

Photodynamic. Resulting from, or pertaining to, the energy of light.

Photodysphoria. (1) Photophobia. (2) Defective vision from excess of sensibility.

Photo-electric. Relating to the production of light by electricity.

Photo-esthetic. Pertaining to or having the sensation of light.

Photofluoroscope. A form of fluoroscope used in making either observations or photographs by means of Röntgen rays.

Photogen. A substance supposed to exist in photogenic bacteria and to be the cause of their luminescence.

Photogene. Same as *after image.* See p. 139, Vol. I of this *Encylopedia.*

Photogenesis. The production of phosphorescence, or the emission of light, as by bacteria.

Photogenic. Of or pertaining to photogeny; produced by the action of light; as, a *photogenic* drawing. Producing phosphorescence; phosphorescent, as fire-flies.

Photogeny. The art of photography.

Photogram. (a) A photograph. (b) The representation of an optical image telegraphically transmitted; a chirographic or pictorial telegram.

Photographic telescope. A telescope, the objective of which is specially designed to bring the photographically active rays to a focus.

Photographometer. (a) An appliance for determining the sensitiveness of photographic surfaces. (b) A pantoscopic camera adapted for surveying purposes.

Photographone. A device for photographing the variations of an electric arc due to sound waves and then reproducing these sounds by means of a selenium cell and a telephone.

Photography, Ocular relations of. Photography is a term that may be taken in a general sense to include any production of pictures by means of chemically active rays (thus, for instance, "Röntgen photographs" are often spoken of). The name, however, means "light drawing," and it would be more correct to restrict its application to such production of pictures as are effected by the chemical action of light rays emitted from, reflected by, or transmitted by the depicted objects.

The source of light in ordinary photographic work is the sun, and it is well known that sunlight contains a number of rays of different qualities, some being invisible and others showing a range of colors from red to violet (see **Light**). Sunlight contains the largest proportion of chemically active rays about noon, and consequently at this time of the day its effect on the photographic plate is more powerful than at other times, though the intensity of light may be the same. If light from any source be passed through red glass or any other trans-

parent material of red color, which absorbs all the rays except the red ones, it becomes almost devoid of chemical activity. In the photographic "dark room," therefore, to which only red light is admitted, plates, papers and other implements or preparations sensitive to light amy be manipulated more or less freely without any change taking place in them.

The chief instrument used in photography is the camera obscura, commonly called the "camera." This consists simply of a box with a hole in one of the end walls in which a lens or system of lenses is inserted, or generally in a tube attached to it. The back wall, as a rule, consists of a frame in which is inserted another removable frame containing a sheet of ground glass, which makes it possible to observe the picture from without. The image appears upside down and reversed as to right and left. The back wall is now adjusted until the image appears with the desired degree of distinctness, and then the ground glass is removed and a flat box ("dark slide," "back" or "sheath") containing the photographic plate is inserted instead. The sliding lid of the "back" may be drawn out after the "back" has been placed in position, thus leaving the sensitized surface of the plate exposed. Before doing this, however, the light coming through the lens must be cut off by closing the "shutter." This may consist merely of a cover overlapping the tube containing the lenses, or more elaborate kind of shutters may be employed, in which latter case their mechanism is often put in operation from a distance by pneumatic transmission of force. Another important measure consists in inserting a diaphragm or stop in the lens tube.

After all necessary preliminaries have thus been completed, the sliding lid of the "back" is drawn out and the shutter opened, thus exposing the sensitized plate to the action of the luminous image projected on it. The time of exposure varies from a very small fraction of a second to several hours according to circumstances. One of the principal difficulties in photographic art consists in choosing the right length of exposure and the correct diaphragm. The chemical activity of the light may be measured by means of an actinometer. (*Standard Encyclopedia.*)

Photography of the fundus oculi. Of the attempts to photograph the details of the background, those of Wolff were among the earliest. He has described his apparatus and methods of photographing the ocular fundus, and published some of the results obtained. The light furnished by the Zeiss projection apparatus is reflected into the eye, through half the pupil, by a mirror made of a special alloy, which allows of a very fine edge. The rays pass out of the eye through the

other half of the pupil to be focussed in the camera. A circle of the retina about 10 mm. in diameter is illuminated at one time, and the picture obtained is about 3.5 or 4 times magnified. The exposure necessary is less than 1/30 of a second. The specimens shown leave something to be desired in the way of definition. Neuhaus and Thorner have written controverting some statements by Dimmer, regarding the photography of the eyeground, to which the latter makes rejoinder.

Dixon has obtained stereoscopic photographs of microscopic eye specimens by making one exposure with the specimen focussed 3 c. m. to one side of the axis of the camera, and making a second exposure with the specimen pushed 3 c. m. to the opposite side of the center. Parker urges the value of photography in ophthalmology, and that every hospital should have a properly lighted and fitted room for the photography of cases.

Robert H. Eliot (*Lancet*, Nov. 11, 1916) has developed the following method of photographing prepared eye specimens which may be of value to the investigator. Elliot regards the following points of importance: The photograph must be taken in water, without the intervention of glass or other similar material. The source of light must be good and even. The camera must be placed vertically above the object so as to avoid reflections. The object of the photograph must be placed so that its image will occupy the center of the plate, and a method of adjustment should be available to secure this end with a minimum of inconvenience. A simple arrangement is necessary to fix the eye in position during the whole period of exposure. To save unnecessary retouching the object should be photographed lying on a dark and uniform surface to obviate the background disturbing the attention of those viewing the picture. Care should be exercised in the choice of a camera and exposure periods must be carefully studied. For the making of lantern-slides the contact method is recommended, and attention is directed to the following points: correct exposure; the preparation of plates for exposure; development and fixation of the slides; the drying of the plates; and the reduction, intensification and varnishing of slides.

Photogravure. The production of a photo-intaglio printing plate on metal.

Photoheliograph. A telescope adapted for solar photography.

Photoheliometer. A device with double lens for measuring by photography and employing the chord common to two images which overlap the variations of the diameter of the sun.

Photohemotachometer. An instrument for recording the changes in the velocity of the blood-current by means of a ray of light passing

through each tube of a differential monometer so as to throw a shadow of the contained fluid on a moving sheet of photographic paper.

Photokatalysator. A name given by Schanz (*Münch. Med. Wochenschr.*, p. 1315, 1915) to those natural living, substances like chlorophyll that are sensitive to the action of light, or that influence light itself. Tissues are said to be, in this relation to light rays, either negative or positive photokatalysators.

Photokinetic. Causing motion by means of luminous rays.

Photologic. Of, or pertaining to, photology, or optics.

Photologist. One versed in photology (optics) or the science of light.

Photology. Optics, the science of the nature and laws of light.

Photo-luminescence. Emission of cold light under the stimulation of light-waves.

Photomagnetism. The science correlating photic with magnetic phenomena.

Photometer. An instrument used for measuring the intensity of light. In addition to what is said on p. 1338, Vol. II, on p. 5226, Vol. VII and on p. 7481, Vol. X of this *Encyclopedia*, it may be added that there are numerous other forms of the photometer, a few of which are here briefly described. The subject is also continued under **Photometry.**

L. O. Grondahl (*Trans. Ill. Engin. Soc.*, March, 1916) in describing his rectangular (also cubical) box integrating photometer, says that the recent development of the concentrated filament lamp and the consequent necessity of rating lamps in terms of lumens or mean spherical candle-power, rather than mean horizontal candle-power, make it seem especially appropriate at this time to consider the subject of integrating-photometers. Of these, the Ulbricht sphere at present holds the field to the nearly complete exclusion of other methods. This integrator has some disadvantages, among which is its first cost, due to the difficulty in making a large spherical surface. This, together with a number of statements in the literature to the effect that a box or an enclosure of any shape whatever would do as well as a sphere, led to a series of experiments on boxes, rectangular and otherwise, in the hope that something would be found to replace the sphere. In order to give a comparison between the performance of the box photometer and that of the sphere, it has been thought advantageous to review some of the results of earlier experiments with the sphere, as well as the experiments of Wild on the box photometer which until very recently had not come to the writer's attention.

The result of the present investigation is to corroborate the statements of those who have said that a box may be used instead of a

sphere. To compare sources of different distributions, however, it is necessary to use a box that is cubical, and its accuracy is still further increased by eliminating the corners and thus approximating a sphere. This being done, and proper precautions being taken in regard to the screen, and in regard to the dark part of the units introduced, the box yields satisfactory results. When the light units all have the same distribution and are similarly oriented with reference to the dimensions of the box, the interior may undoubtedly have any shape. Very recently it has come to the author's notice that a construction similar to the one used in this work had been suggested earlier, and has in one case been applied practically.

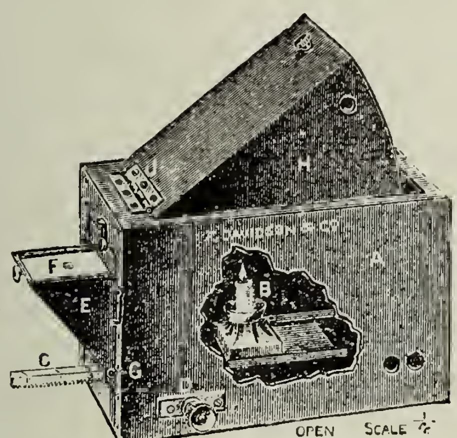
Forster's photometer is a box one-third of a meter long by one-quarter broad and one-sixth high painted black on the inside. On one side are two small holes with a curtain to shut off one eye at a time. Next these holes is a window covered with oiled paper and so arranged that by means of a screw a square hole of any desired size can be adjusted at the window. The size of this hole can be read off on a scale. The window admits light from an adjoining compartment in the box. On the wall opposite the small holes are black marks on a white background. The test consists in deciding the size of square window at which the black marks on the white background become visible. See p. 7482, Vol. X of this *Encyclopedia*.

A school photometer. Nowadays the school physician is expected to do many things besides inspect the pupils of the schools he visits. One of the most important of his duties is that of examining the classrooms in which the school work is done, as regards lighting, ventilation, etc. The examination of the lighting of classrooms both for desk and blackboard illumination is one of the first importance.

A photometer (see the figure) was devised for this purpose by N. Bishop Harman (*Brit. Med. Jour.,* Nov. 4, 1911) and is based upon Bunsen's grease-spot photometer; that method of measuring relative illumination is well known to laboratory workers, and it is the basis of most forms of photometers. It is, however, not suitable for school use, since it is not readily portable, nor adapted for measuring the illumination of horizontal surfaces. In this new instrument a standard sperm candle is mounted within a box, A. The top of the box is hinged at J, and lifts so as to form a chimney and guard, H. The front of the box is in part hinged at G, so that it can be brought out to form a platform, E. The flat top of the platform is cut with a circular hole, which in use is covered with a sheet of very thin paper, F. The interior of the platform has fitted with it a card reflector set at an angle of 45 degrees to the flame of the candle. The candle holder is fixed upon

a stage which slides in grooves, and to this stage is attached a rack and pinion gearing, so that the candle can be moved forwards and backwards in relation to the screen by turning the milled wheel, D.

When it is proposed to measure the light falling upon a desk, the box is placed thereon, the lid opened, and the candle lighted; then the lid is set at an angle to serve as chimney and guard. Now the front platform is turned out so as to expose the white paper screen to the light of the room. The milled wheel is turned to bring the candle forward until just sufficient light is reflected upon the under surface of the screen to cause the central area to appear slightly whiter than the rest of the paper, like the full moon behind a thin cloud; with a very little practice one gets expert in judging this point. The candle,



Bishop Harman's Photometer for School Doctors.

in the particular position and conditions of reflection, just overbalances the light falling upon the screen from above. The ratchet which draws forward the candle is protruded from the front of the box, C, coincidently with the movement of the candle; its flat surface is graven with a scale marked in foot-candles from 1 to 16 candles, so that the illumination of the desk can be read off in the usual English terms (the correction for the Continental standard "meter-candles" is given). Further, the minimum illumination required for classroom purposes is marked separately on the sides of the scale; the minimum for daylight has been fixed at 9 foot-candles and for artificial light at 3 foot-candles. Between the reflector within the front platform and the candle is a blue-green filter glass, to absorb the yellow rays of the candle flame and give the reflection upon the screen a clean white tint. The reflector

is made of plain white card, so as to be easily renewable. The paper used for the indicator screen is fine mat-surface parchment paper, so that it is also easily renewed. The source of illumination is a London sperm standard candle (six to the lb.); a candle has an advantage in that the instrument is ready for use at any time, whether the periods of its use be frequent or separated by long intervals. The photometer when closed measures 8 by 5 by 3 in., so that it is handy. The new photometer has been found convenient in use, and accurate within the requirements of the purpose for which it is designed.

A photometer has been described by Hammer, which depends on the influence of light on the transmission of an electric current through a selenium cell. Schoute has combined, with the lamp of Donders for testing the light and color-sense, apparatus for the detection of simulation.

Photometric units. Standards of light intensity.

The *Electrical World* (*Prac. Med. Series*, p. 17, 1910) says that the unit of light at the Bureau of Standards, Washington, has been maintained through the medium of a series of incandescent electric lamps, the values of which were originally intended to be in agreement with the British unit, being made 100/88 times the Hefner unit. The unit of light at the Laboratoire Central, Paris, is the bougie decimale, which is the twentieth part of the standard defined by the International Conference on Units of 1884, and which is taken, in accordance with the experiments of Violle, as 0.104 of the Carcel lamp. The unit of light at the Physikalisch-Technische Reichsanstalt, Berlin, is that given by the Hefner lamp burning at normal barometric pressure (76 centimeters) in an atmosphere containing 8.8 liters of water vapor per cubic meter. The unit of light at the National Physical Laboratory, London, is that given by the 10-candle-power Harcourt pentane lamp burning at normal barometric pressure (76 centimeters) in an atmosphere containing 8 liters of water vapor per cubic meter. Proposed new unit = 1 pentane candle = 1 bougie decimal = 1 American candle = 1.11 Hefner unit = 0.104 Carcel unit. Therefore, 1 Herner unit = 0.90 of the proposed new unit. The pentane and other photometric standards in use in America will hereafter be standardized by the Bureau of Standards in terms of the new unit. This, within the limits of experimental error, will bring the photometric units for both gas and electric industries in America and Great Britain and for the electric industry in France, to a single value, and the Hefner unit will be in the simple ratio of 9-10 to this international unit. The attitude of the electrical and gas interests towards the new unit is discussed and its difficulties and advantages mentioned.

Photometrician. PHOTOMETRIST. One who is versed in photometry.

Photometry. An important practical branch of optics, the fundamental idea being the comparison of the intensities of two lights or luminosities. The principle of the methods in general use is to arrange the two sources of light so that their luminous effects on two contiguous surfaces, or on one and the same surface, appear to be equal. The eye is the judge of this equality of brightness; and when it is obtained the intensities of the lights themselves are taken as being proportional to the squares of the distances of the respective lights from the illuminated surface or surfaces. This is in accordance with the law of radiation that the brightness of a light appears to diminish as the square of the distance increases. One of the oldest and simplest photometers is to throw the shadows of a rod as produced by the two lights on a white screen, and adjust the one flame until the shadows appear of the same darkness. A very important method of recent date is to illuminate a given surface first by the one light and then by the other in rapid alternation. This in general produces a flicker, which disappears when the luminosities are exactly equal. This is the principle of the flicker photometer, as it was called by Rood, of New York, who first showed its efficacy. The great development of electric lighting and the necessity for having an accurate test of the candle-power of a lamp has led to the manufacture of many forms of photometer, both of the comparison and flicker type. When the lights are of the same or nearly the same color the comparison is easy and gives good results; but when they are of different colors the ordinary methods of comparison are not satisfactory. In such cases it is found that the flicker method is more constant in its results, the personal error of the observer being least marked. The older method of diminishing the intensity of illumination produced by a light, by changing the distance of the light from the surface, has been largely replaced by a method of cutting down the energy of the radiation without moving the source of light. One of these methods is to polarize the rays and then, by means of a rotating Nicol prism, cut down the intensity of the stronger ray. Another method is to pass the stronger ray through a rotating disk with perforations of adjustable size. By either of these methods the operator can bring the luminosities to equality without moving the sources of light from their positions. Each civilized country has its own photometric standard, which is fixed by statute. No absolutely constant standard capable of being accurately reproduced at will has been discovered; probably the Hefner-Alteneck amyl-acetate lamp used in Germany best fulfils the practical conditions of a standard light.

The English standard candle is sufficient for most practical purposes. (*Standard Encyclopedia.*)

Color photometry. The *Electrical World,* July 15, 1916, says that since the establishment of the international candle in 1909 this unit has been maintained at the Bureau of Standards in Washington solely by means of a group of 4-w.p.c. carbon-filament incandescent lamps. With the advent of the tungsten lamps there was introduced into standardization work the difficulty of comparing lights of different colors, and at once it became desirable to have the unit well established also in tungsten lamps operated at or near their normal color.

In 1911, by common agreement between the National Physical Laboratory of England and the Bureau of Standards, each laboratory prepared a group of tungsten standards calibrated for voltage corresponding to approximately 1.5-w.p.c. These two groups of lamps, which were thus operated at very approximately the same color, were then exchanged, and each group was remeasured by the receiving laboratory at the voltage determined by the sending laboratory. A group, similar to the one sent to England, and standardized in the same series of measurement was retained at the bureau, and half of the group received from England, after measurement was returned for remeasurement.

In view of the difficulties involved in the intercomparison, the result was very satisfactory, as it showed that the two laboratories were in agreement to within the indicated precision of the measurements. In both laboratories the new standards were measured by means of Lummer-Brodhun contrast photometers of the standard type, and in terms of similar groups of 4-w.p.c. carbon standards, the English laboratory having made the comparison by the cascade method, the Bureau of Standards by the use of two calibrated blue glass screens, each of which produce a color match between the two groups of standards compared. It is obvious, therefore, that the calibration of the glass screens used by the bureau in this intercomparison was a matter of prime importance, and for this reason a large amount of work has been done in checking, by various methods, the values first assigned.

In connection with these check measurements, and after a determination of the candle-power and current of a group of tungsten substandards at several voltages had been made, and this followed by a further investigation of other groups of tungsten lamps, the voltage-current-candle-power curves were determined and accurately expressed by means of equations. It was found that by employing these equations it is possible to measure tungsten lamps in color match with 4-w.p.c. carbon standards and compute with accuracy their value at any other

color within the range investigated. In this way, as well as by direct comparisons, the new tungsten standards have been rechecked a number of times by different groups of observers.

These equations have an important application also in the life testing of tungsten lamps, because in some testing laboratories it is customary to photometer the lamps at or near rated voltage and compute the voltage corresponding to the efficiency at which it is desired to burn the lamps on life test.

In the establishment of the 1.5-w.p.c. tungsten standards, and also in the determination of the characteristic equations, the photometric measurements of necessity involved color differences. Although numerous check measurements have been made and the results have been very satisfactory, it is, of course, realized that if some other group of observers had made these measurements the values obtained might have been different.

It was, therefore, suggested that an inter-laboratory photometric comparison of lights involving color differences such as those encountered in these measurements would yield valuable information not only as to the agreement which might be reasonably expected among different groups of experienced observers, but also information as to the merits of different methods of making such measurements.

The Bureau of Standards, therefore, in May, 1914, invited several of the more important photometric laboratories of the country to co-operate with it in making measurements of this kind. The Nela Research Laboratory, the Electrical Testing Laboratories and the Physical Laboratory of the United Gas Improvement Company accepted this invitation, and the results of this very interesting co-operative research are given in Scientific Paper 277 of the Bureau of Standards, entitled "An Inter-Laboratory Photometric Comparison of Glass Screens and of Tungsten Lamps, Involving Color Differences," by G. W. Middlekauff and J. F. Skogland. As to the detailed results of these tests the reader must be referred to the tables and diagrams in the original bulletin.

The most interesting general and quite conclusive result of this intercomparison is that in each laboratory, regardless of the kind of photometer used, even though a considerable color difference was involved, each observer maintained a fairly constant criterion with respect to the mean. The same is true of each laboratory in respect to its relation to the mean of all, as judged by the measurements on the glass screens and those made on the lamps some months afterward.

Considering the difficulties involved in the measurements, the different characteristics of observers and the wide difference in illumin-

ation employed, covering probably a range of ten times, the agreement among the laboratories is remarkably good.

It is evident, therefore, that measurements to establish standards involving a color difference should be left as much as possible to the standardizing laboratory, where the observers must be carefully selected and a considerable number employed and the instruments and conditions of illumination, etc., definitely fixed.

An examination of the bureau's observers who took part in this work shows that their mean characteristic is very approximately the same as that of the "average eye," as determined from a test of 114 observers taken at random from the bureau's scientific staff.

Photometry of colored lamps. To find a correct method of monochromatic comparison of lights of different colors, the principle employed involves the use of a filter which eliminates color effects but permits light to pass so that the ratio of the two intensities is the same as that of the total intensities. For ordinary incandescent lamps this is fulfilled by the use of a filter which permits the wave lengths 570 to 575 mm. to pass. The mean values of the measurements differ from those obtained without the filter by only 1 per cent. It is therefore permissible to compare by this means standard lamps worked at low intensities and producing yellow light with those operated at high rates of output and giving bluish-white light.

Photomicrograph. A macroscopic photograph of a microscopic object.

Photomicrography. The photography of optical images enlarged beyond the dimensions of the objects which they represent.

Photonephograph. Photonephoscope. A photographic apparatus for determining the distances of moving clouds by triangulation.

Photonosos. Photonosus. An affection of the sight, as snow-blindness, resulting from exposure to a glare of light.

Photoparesthesie. (F.) An extraordinary tolerance of light on the part of the visual apparatus, so that the person affected is capable, for instance, of gazing at the sun.

Photophobia. Intolerance, or dread, of light, generally the result of widely dilated unprotected pupils, hysteria or some inflammatory disease of the cornea, uveal tract, retina or optic nerve.

Fuchs (*Wiener Klin. Wochenschr.* Jan. 1912) defines photophobia as a disagreeable sensation of dazzling, which may be intensified so as to cause real pain, with lachrymation and spastic closure of the lids; in many individuals causing, besides, sneezing. These symptoms are reflex in which the centrifugal part of the arc is formed by the facial nerve for blepharospasm and probably for lachrymation, and by the motor nerves of respiration for sneezing. The centripetal part of the

reflex arc is either the fifth or the optic nerve. The great majority of cases are due to irritation of the fifth nerve. Strictly speaking it is, at any rate in the opinion of the reviewer, doubtful if the term photophobia correctly describes these cases, but it has been in use in this way for so long a time that its original meaning must not be taken too literally.

In the treatment of the very obstinate cases met within ordinary phlyctenular affections Fuchs speaks highly of dionin, and also of Bier's treatment with a suction apparatus. He explains the favorable action of this treatment by suggesting that the action is somewhat similar to the production of Schleich's infiltration anesthesia in which the edematous inhibition of the tissues acts as an anesthetic on the fine nerve endings.

The author then goes on to discuss the genuine cases of photophobia in which the optic nerve acts as the centripetal part of the arc. He explains the pain that may be felt on exposure to very bright light as due to the pull on the nerve fibres of the iris by the strong contraction of the pupil. This opinion is based on an experiment he made on himself when studying snow-blindness. He found that when he went out of a dark hut on the sunlit snow he felt dazzling and pain, but that when the pupils had been dilated with homatropine no pain was felt, since although the quantity of light entering the eyes was greater, the pupil could not contract. He points out that the modern fashion of prescribing yellow glasses is not altogether satisfactory, as in lower altitudes under ordinary conditions the quantity of ultraviolet rays present is but small, and that protection is really required from the visible rays of the spectrum.

The difficulty in seeing experienced by the totally color-blind in bright light is explained by the author on the basis of the Parinaud-Kries theory as due to deficiency in the retinal cones. See, also, **Light effects on the eye**, p. 7474, Vol. X of this *Encyclopedia*.

Photophobophthalmia. Nyctalopia.

Photophone. This device is a comparatively simple apparatus which may be said to achieve the feat of transmitting articulate speech to a distance along a beam of light. The success of the photophone depends on the peculiarities of the metal selenium. Crystalline selenium offers a high degree of resistance to the passage of an electric current; it is eminently sensitive to light; and the resistance is less when exposed to light than in the dark, being in some cases only a fifteenth in the light of what it is in the dark.

In the photophone found most serviceable the transmitter is a plane mirror of silvered microscope glass or thin mica; the receiver, fixed

at a distance without any connection, is a parabolic reflecting mirror, in the focus of which is placed a sensitive selenium "cell," connected with a battery and telephone. When the apparatus is used, a strong beam of light is concentrated by a lens in the plane mirror; the speaker directs his voice against the back of the mirror, which is thrown into vibrations corresponding with those of the voice. The reflected beam of light is directed through a lens to the receiving mirror and creates in the selenium cell a rapidly variable current, which at the end of the telephone attached becomes audible again as vocal sound. (*Standard Encyclopedia.*) See, also **Bell's photophone**, p. 928, Vol. II of this *Encyclopedia.*

Photophore. An electric hand lamp or torch for diagnostic purposes and for use as an illuminator in operations, generally on the eye, ear, nose and throat. Many of these are shown under various captions, such as **Lamps, Ophthalmic,** p. 6998, Vol. IX, and **Examination of the eye,** p. 4605, Vol. VI of this *Encyclopedia.*

Photophosphorescent. Exhibiting phosphorescence under the influence of light.

Photophthalmia. Any disease of the eyes—*snow-blindness, lightning stroke, solar cataract, asthenopia, eclipse ophthalmia*—from undue exposure to sunlight. The affections just mentioned are described under their separate headings.

G. E. de Schweinitz (*Trans. Coll. Phys., Phila.*, Oct. 16, 1913) after a description of various types of photophthalmia (the term introduced by Parsons), recites the case-histories of patients who, after exposure to various sources of bright light, and after the subsidence of the photophthalmic symptoms, continued to suffer for long periods of time from persistent asthenopia, characterized by violent headache, excited by any effort of accommodation or the least exposure to light.

de Schweinitz, in endeavoring to explain these symptoms, discusses the ocular effects of the prolonged action of ultra-violet, infra-red, and visible rays. The sources of light, the exciting agents of these asthenopic symptoms, were in one case an open-hearth steel furnace, in another a powerful electric headlight, and in a third the glare from wide stretches of desert sand. These cases were used as types. It seems to de Schweinitz that when the ultra-violet rays are most to blame the symptoms are somewhat different than when the offending rays are the infra-red or visible rays, particularly as regards the field of vision, which exposure of the ultra-violet rays especially disturbs. He is aware, however, that the division is to a certain extent an artificial one, and he can not be sure that such a separation of the effects of the various rays can always be made. It does seem to him, however, that

one important source of the pain arises from a disturbance of the function of the ciliary body which is long in subsiding, and while it lasts appears to be responsible for the severe ciliary neuralgia and headache which follow when this muscle is contracted in the effort of accommodation.

In the treatment of these cases prolonged mydriasis is advocated, under the influence of which the irritability and the hyperemia of the ciliary region subside; thus the examiner is enabled accurately and fully to correct any anomaly of refraction, and this correction and the insistence that the glasses be constantly worn are important parts of the treatment, but apparently not entirely sufficient. Therefore he has tried the effect of various drugs, notably iodides and bromides, but thinks that his best results followed the persistent use of satisfactory preparations of cannabis indica.

Photophysical. Pertaining to the physical effect of light; opposed to photo-chemical.

Photopia. A name given by Mrs. Ladd Franklin to daylight vision; state of bright-light adaptation of the retina.

Photopolarimeter. A name given to a form of polarimeter.

Photopsia. Photopsy. Phosphenes. An affection characterized by subjective sensations of light, such as sparks and flashes of fire, due to disease of the optic nerve and retina. They may also be caused by sudden pressure or blows on the eyeball.

A review of a paper on this subject by Calderaro (*La Clinica Oculistica,* March, 1909) is given in the *Ophthalmic Review* for Sept. 1909. The writer reminds us that under ordinary conditions photopsiæ are generally considered to take their origin in the retina, or—in other cases—in the cerebral cortex (as in scintillating scotoma), and it only occasionally happens that we may meet with a person who after enucleation is still annoyed by photopsiæ, and that to a serious extent. In such cases the stump of the optic nerve may be involved in the conjunctival cicatrix or in a patch of chronic inflammation of the orbital tissues. In one case of this kind Calderaro had observed the symptoms carefully and had examined too the enucleated eyes and small portions excised from the stumps of the optic nerves (there are almost no similar cases in literature). His case was that of a man of 50, a shopkeeper, who had never enjoyed good sight. In subdued light particularly his sight was very imperfect and he had to be led about after sun-down, though in a good light he could read and write. He was a nervous, excitable man, but with no disease of note, or history of any such; he was married and had three healthy-looking sons.

Six years ago the right eye began to have attacks of subacute glau-

coma of "emotional" origin; these became more and more frequent and severe, gradually destroying vision in spite of treatment by miotics, iridectomy, etc. It was during this period that the patient first began to be annoyed by photopsiæ and chromatopsiæ in this (right) eye; at first these photopsiæ were present only during the attack of glaucoma, but latterly they became constant and were the cause of great annoyance to him so much so that in hope of getting rid of them he at length submitted to evisceration of the right eye—already blind and, at times, very painful. Most unfortunately, however, even after the operation, the photopsiæ were just as troublesome as before, and the condition of glaucoma persisted in the remaining eye. The notes as to the condition of that (the left) eye, taken in September, 1904, describe slight congestion of the anterior ciliary veins, a transparent but slightly anesthetic cornea, shallow anterior chamber, dull iris with immobile pupil, rather oval in shape, the vitreous slightly turbid, and the disc pale and cupped; the arteries in the fundus narrow and thready, irregular black pigment patches scattered chiefly along the course of the vessels and particularly about the equatorial region. The tension was somewhat increased and the field of vision much narrowed concentrically; vision = counting fingers at 4 M. In the right orbit the remaining stump after excision was slightly tender, both spontaneously and on pressure. It was thought better to recommend removal of the stump, which was .carried out, the nerve being cut across about 1 cm. posterior to the remains of the eye. At the same time pilocarpin was employed, and vigorous general treatment, with the result that the glaucomatous symptoms in the right eye became decidedly lessened, though the light-sense showed little actual improvement. Indeed, matters rather grew worse, and in less than a year the retinitis and glaucoma together had practically extinguished all sight. The unfortunate patient began then to suffer from severe left-sided hemicrania, which together with the photopsiæ rendered his life so miserable that at last induced Prof. Francaviglia to enucleate that eye also in May, 1907. The operation did not, however, bring about entire relief, for though the pains in the head were greatly assuaged the photopsiæ remained, and presently the headaches returned, left-sided at first but later over all the head.

As regards the photopsiæ, the patient describes himself as though seeing a (pale or dark) red-colored fluid moving in a wavy fashion in the left half of the field of vision; the movement takes place in all directions, but chiefly from above downwards. At another time it seemed as if the movement took its origin in the orbit, the flashes darting out from the centre of the left orbit and spreading in all

directions, and having a reddish coloration, always most intense when the symptom was most obstrusive. As a rule the left hemicrania was less while these photopsiæ were at their maximum, and vice versa.

Examination of the patient disclosed no signs of hysteria, or any indication of disease of any organ; the orbits were quite healthy to all appearance. But no means which Calderaro could devise, no drug which he instilled into the conjunctiva, injected into the orbit, or introduced into the system, and no variety of electric current, had any effect in mitigating to more than a slight degree the severity of the subjective symptoms. Finally he injected cocain, dissected out the nerve and removed as much of it as he could get hold of, but again without result. Before the actual removal, he waited for a few minutes till the effect of the cocain had passed off, and tested the sensitiveness of the optic nerve, but moderate pressure on it with forceps excited no luminous sensation on the part of the patient, and no pain; the actual section of the nerve, or rather of the sensory filaments accompanying it, was attended with sharp pain. Removal of the stump of the nerve made not the slightest difference to the pain and photopsiæ, and though in one of the nerves there was more complete atrophy and breaking down of the nerve elements than in the other there was in neither any suggestion of cicatricial compression or of chronic inflammatory change.

The facts being as above stated, there being no sign of ascending atrophy (even if a process so definitely negative could be supposed capable of giving rise to a positive reaction such as photopsiæ), and no collateral or other evidence of any fascicular cerebral alterations, Calderaro finds himself forced to the conclusion that the seat of the irritation must have been the visual cortex.

Photoptometer. A device for testing the acuity of vision by determining the smallest amount of light that will render an object visible; a photometer.

Photoptometry. The determination of the degree of illumination requisite for the recognition of an object.

Photoradiometer. An apparatus for measuring the quantity of X-rays penetrating any given surface.

Photoreaction. A term proposed by M. Starub and others to designate the mechanical act of vision, apart from consciousness. See **Conscious vision,** p. 3184, Vol. V of this *Encyclopedia.*

Photoret. A small photographic camera.

Photorrhexis. (L.) Refraction of light.

Photoscope. An instrument for measuring intensities of light by making use of the property of a material, as selenium, that has a varying electrical resistance with varying degrees of illumination.

An apparatus in which photographs are arranged so as to be conveniently seen through magnifying lenses.

A contrivance by which a series of motion photographs of a speaker's lips are employed in the instruction of deaf-mutes.

A form of the fluoroscope. See p. 5232, Vol. VII of this *Encyclopedia.*

Photoscopy. The same as skiascopy.

Photosphere. The luminous shell emitted by the gaseous globe surrounding the sun. An orb of light or radiance. One of the many luminous, eye-like organs about the bases of the legs in certain schizopods: formerly called accessory eyes.

Photostat. An automatic light regulator, e. g., the iris of man and some other animals. This term was suggested by C. F. Prentice, but it is commonly applied to a form of photographic instruments from which negative prints of objects are obtained.

Phototachometer. A device for the measurement of the velocity of light by means of a rotating mirror.

Phototactism. The stimulus of light on the movements of protoplasmic masses in plants.

Phototaxis. The taking up of a definite position by a plant-organism or member with reference to the direction of the incident ray of light, being *negative phototaxis* or *aphototaxis* when the movement is away from the light and *positive phototaxis* when the movement is toward the light.

Phototelegraph. An apparatus for the reproduction of optical images at a distance.

Phototheodolite. An instrument for the performance of triangulation by means of photographs.

Phototherapy. The treatment of disease by the influence of light, especially by variously concentrated light-rays. See **Radium, X-ray, Blue light,** and **Heliotherapy,** p. 5736, Vol. VIII of this *Encyclopedia;* also consult **Finsen lamp,** p. 5203, Vol. VII.

Wood (*Ophthalmic Therapeutics,* p. 96) quotes Sydney Stephenson's review of the subject to date. L. Koch (*Münch. Med. Wochenschr.,* Sept. 18, 1906) obtained good results in nineteen cases of keratitis, of serous iritis and of corneal scars by exposing the eye twice a day for about five seconds to the light of a 20 candle-power electric lamp. Frank's experiences with the chemical rays of light in various forms of keratitis were encouraging. He used the voltaic lamp of which the heat rays were arrested by passing the light through a saturated solution of copper sulphate. The eye was placed at the focal distance of a convex lens, by means of which the rays were concentrated.

D. E. Sulzer (*Annals d' Oculist.,* Nov. 1906) attempted to remove

opacities of the cornea by exposure of the eye to the radiations from an arc-lamp. The eye was placed at the conjugate focus of the arc-light formed by a quartz lens, which had a diameter of 40 mm. and a principal focal distance of 50 mm. The exposure varied from 20 to 90 seconds, but essentially depended upon the reactional suceptibility of the patient. Reaction was proportional to the length of exposure to the actinic rays. It supervened in from two hours to two days after treatment under the guise of redness of the eye, lachrymation, and lancinating pains. Sulzer found that interstitial scleroses of the cornea improved. He made the important observation that under the influence of the treatment, tension falls, pupillary exudations become absorbed, and posterior synechiæ undergo rupture. Nineteen cases were quoted in support of Sulzer's conclusions.

Hertel (Graefe's *Arch f. Ophth.*, July 16, 1907) has given much attention to the treatment of *ulcus serpens corneæ* (hypopyon-keratitis) by this means. Of 547 cases experimented on, 26 were cured with the light rays, derived from a kind of modified Finsen lamp and an amalgam of cadmium and zinc, with an arc of 3 mm. to 4 mm. at 2.5 amperes. Exposure ranged from three to five minutes, and, as a rule, several sittings were required. Reaction was pronounced. It was noted, and the point is practically important, that the resultant scarring was very slight after the treatment of hypopyon-keratitis by irradiation.

The *Jour. Am. Med. Assoc.* Aug. 14, 1915, again calls attention to the dangerous influence of prolonged exposure of the body to bright sunlight in those who have not been accustomed to its rays. Grawitz called the attention to this danger some years ago. Römer says that lying on the sand for hours in the sun has become such a popular pastime that at a single one of the Hamburg resorts there were 18,000 taking the sun bath one Sunday. The damage is more than the sunburn resulting, as he shows by two cases reported in detail, in which headache and symptoms of meningitis developed after the youths had been lying several hours in the sunlight with unprotected heads and no clothing but bathing trunks. Spinal puncture confirmed the assumption of meningitis and relieved the headache. The sun's rays had evidently penetrated the skull, he says, thus demonstrating that sunstroke is the consequence of direct exposure to the sun. Grawitz warned that those inclined to be nervous were particularly predisposed to injury of the nervous system from this cause, and Römer adds that it is the anemic and nervously predisposed city indoor workers with whom these sun baths are most popular. A tanned and vascular skin, is said to protect better against injury from the sun's rays, but the

city dweller's skin is neither pigmented nor vascular. Instead of being benefited, the nervous are rendered more nervous, and when the summer is over they are tanned but otherwise in poorer condition than in the spring. No one welcomes more than the physician the "back to Nature" tendency of recent years, but it is his task to warn against excesses and abuses in the "enjoyment of Nature." Even Rollier, the most expert and most successful adherent of heliotherapy, manages the exposures to the sunlight with extreme care, exposing only slowly and gradually larger and larger areas of the body to the sunshine. Dorno relates that "at Davos the direct sunlight is avoided almost as something inimical." Römer remarks that the physician will only in rare instances be able to influence the popular "sun baths sports," but he can at least raise a voice of warning of the dangers of sun baths, and urge the necessity for proper dosage, some persons being more sensitive to the sun's rays than others.

Photothermic. Denoting the thermic activity of light-rays.

Phototonus. A term employed by Sachs to denote the tonic influence of light upon the protoplasmic movement and the growth of plants, or the condition thus induced; especially noticeable when growth that has been arrested during prolonged darkness is renewed after admission of light.

Increased irritability or motility induced by exposure to light in contrast with rigidity or quiescence as a result of darkness.

Phototraumatism. Injury to the retina and other parts of the eye from excessive light, as in glaring, from solar eclipse, electric arc lights, electric furnaces, lightning, etc. See **Glaring,** and other similar headings.

Phototrichromatic. Of or relating to color-photography in which three colors are used.

Phototype. A photographic negative.

Photovisual. Denoting a lens that directs the actinic and non-actinic rays to a common focus.

Phtheiriasis. PHTHIRIASIS. Infestation with lice. See **Pediculosis.**

Phtheiriasis ciliorum. Lousiness of the eyelashes, the lice being attached to the base of the cilia and depositing their eggs there. See **Lice,** p. 7441, and **Louse,** p. 7546, Vol. X of this *Encyclopedia,* also **Parasites, Ocular.**

Phtheiriasis palpebrarum. Infection of the edges of the lids by lice.

Phtheiriasis superciliorum. Lousiness in which the parasite is found on the hairs of the eyebrows.

Phthiriasis. PHTHEIRIASIS. See **Blepharitis pediculosa.**

Phthisis bulbi. See **Atrophy of the eyeball,** p. 667, Vol. I of this *Encyclopedia.*

Wicherkiewicz (*Clinique Ophtal.*, Sept. 10, 1908) because of the fact that in a phthisical globe the recti muscles cause deep grooves and consequent pressure on the ciliary nerves, thus provoking a danger for the other eye, proposes in certain cases to tenotomize the four recti.

Excluding those cases in which enucleation of the injured eye is imperatively called for (e.g., foreign bodies, neoplasms, parasites, irregular cicatrices in the region of the ciliary body) and including cases of phthisis bulbi due to metastatic or traumatic iridocyclitis or uveitis, the writer has satisfied himself that the operation is decidedly useful for three reasons.

From the cosmetic point of view, after the operation the small globe becomes more prominent; if the atrophy have not gone too far it becomes quite as prominent as its fellow; if there is a strabismus it disappears; the mobility of the globe is unimpaired. Secondly, the muscular pressure upon and the sensitiveness of the injured eye cease while the danger of sympathy in the other eye is diminished. Even if sympathetic ophthalmitis has already appeared it diminishes in intensity after the operation. Thirdly, an atrophying eye not only regains its form and more or less its position but its perception of light becomes prompter and more exact.

The method of operating is very simple; after cocainizing the eye a subconjunctival injection of novocain and adrenalin is made in the direction of the four recti. Then the conjunctiva is divided carefully round the cornea and dissected up a little. The four recti are hooked up and divided at their scleral insertion and finally a circular suture draws the conjunctiva up to the cornea. The suture is removed in three to five days.

Phthisis corneæ. Phthisis bulbi anterior. In cases marked by extreme ulceration the entire cornea, except a narrow area at the periphery, may succumb. Such an extensive sloughing process is naturally attended by complete prolapse of the iris. The cornea becomes replaced by a perfectly flat scar, considerably smaller, however, than the normal.—(J. D. L.)

Phthisis, Ocular signs of. The ocular metastases that may occur in pulmonary tuberculosis have been referred to many times in this *Encyclopedia.* J. L. Tuechter (*Jour. A. M. A.*, Feb. 24, 1912) speaks of unequal pupils as an early sign of unilateral pulmonary tuberculosis, due to enlargement of the bronchial glands and the consequent pressure upon and stimulation of the sympathetic fibers in the affected locality.

The writer says that in a large majority of the eases in which the sign occurs, the pupil is wider on the side of the pulmonary involvement, and this led Geza Fodor, who first described this phenomenon, to the belief that the reaction is due to a stimulation of the sympathetic nerve fibers, causing on that side a spastic mydriasis. Nevertheless, in many cases the opposite is true, namely, that the pupil of the unaffected side is wider, and it is this fact whieh led many observers to discard the phenomenon as having no definite value. It remained for Leo Wolfer to determine the real cause of the pupillary difference. He came to the conclusion that the widening of the pupil is due to a stimulation of the sympathetic fibers caused by pressure exerted by enlarged bronchial glands of the affected side.

For this reason it is not necessarily observed in the pupil corresponding to where our objective findings lead us to locate pulmonary process, in so far as the glands on this side are not invariably and of neeessity sufficiently enlarged to stimulate the corresponding sympathetic fibers.

After observing a large series of cases Tuechtner has been able to substantiate these latter findings, and he is satisfied that a eomparative dilatation of one pupil signifies an enlargement of the bronchial lymph-glands of the corresponding side. As such glandular involvement is usually tuberculous in character and takes place at a time when the lung itself does not as yet show destructive changes, this sign is most valuable in the early diagnosis of pulmonary tuberculosis. Before drawing a definite conclusion as to the significance of this phenomenon, it is of course necessary to rule out affections of the eye which may cause pupillary differences, as well as certain conditions of the thorax, such as tumor or aneurysm.

Tuechtner does not refer to the work of Rampoldi, published in the *Annali di Ottalmologia* some twelve or fifteen years ago. This paper was translated and commented on by the Editor and reviewed in *American Medicine* at the time.

Phylacogen. A trade preparation, said to be a filtrate of bacterial cultures which when injected into the body, tends to stimulate the formation of specific defensive proteins.

V. A. Deeot (*Buffalo Med. Jour.*, Aug., 1915) claims that of many cases of gonorrheal iritis and conjunctivitis, rheumatic iritis, postoperative iritis following cataract extraction, ophthalmia neonatorum, and similar diseases treated by him with phylacogen, the great majority have been entirely successful, and the treatment has come fully up to expectations. The percentage of cases in which relief was prompt and certain was much greater than that obtained after the usual remedies,

and benefit was obtained under conditions that left little doubt that the results might properly be credited to phylacogen therapy.

Phyllanthus niruri. An East Indian species of plant. The juice of the stem, mixed with oil, is used in ophthalmia.

Phylogeny. A biological term applied to the evolution or genealogical history of a race or tribe. It is used in contrast to "ontogeny"—the development or life-history of an individual; witness Haeckel's "biogenetic law": "Ontogeny is a recapitulation of phylogeny." (*Standard Encyclopedia.*)

Phyma hordeolum. Hordeolum, or stye.

Physiatrics. An old term for the curative forces of nature.

Physick, Philip Syng. An early American surgeon, renowned as an operator on the eye, especially for cataract and artificial pupil. Born in Philadelphia in 1768, he there received his early education, and later a collegiate training at the University of Pennsylvania. After about three years of study with a Philadelphia preceptor, he became, in 1789, a student of surgery at London, England, being in fact a private pupil of John Hunter and living in his house. In 1791 he went to Edinburgh, and one year later received at the Edinburgh University his doctorate in medicine.

Returning to Philadelphia, he became at once successful. In 1794 he was appointed surgeon to the Pennsylvania Hospital; six years later, lecturer on surgery at the University of Pennsylvania, and, in 1805, full professor of that subject. In 1818, however, he resigned this chair to accept the chair of anatomy—a position which he held till 1830.

Physick was the first to suggest the use of animal ligatures in surgery. He also invented the tonsillotome, and was first to use a syringe and gum elastic catheter for the purpose of washing out the stomach in cases of poisoning. He invented a punch-forceps, wherewith to remove a piece of the iris for artificial pupil.

As a writer, he was almost sterile.

As a teacher, he was methodical and clear, but so cold, distant and forbidding in his manner that his pupils disliked him. He was of middle height, pale, solemn and dignified.

He died in Philadelphia in 1837.—(T. H. S.)

Physick's iridectomy. See **Operation, Physick's**, p. 8487, Vol. XI of this *Encyclopedia.*

Physiological diplopia. Double vision produced by an abnormal degree of convergence of the optic axes with reference to the amount of accommodation brought into a not infrequent condition in some forms of anomalous muscular dynamics of the eye.

Physiological optics. [Owing to the size and importance of this section a table of contents is herewith prepared. Many of the sub-captions have already been to some extent treated in this *Encyclopedia,* but from a viewpoint differing somewhat from the treatment accorded them here. Ed.]

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INTRODUCTION

The domain of science has its many branches and they are veritably members one of another. Chemistry, with its unions of atoms and physics, with its fundamental molecule and its later concept, the electron, have found a common ground and meeting place in physical chemistry. These interminglings and correlations of the sciences have always been productive and fruitful. Physiologic optics is no exception to this statement for it forms the bond of union between the science of life and the functions of the human regime and that inanimate and invisible something which we call light or, more broadly, radiant energy. These radiations, transmitted by an elastic medium, designated as the ether, in the form of transverse waves at a velocity of approximately 186,000 miles a second, are received by the human system and furnish it external sources of heat, aid in metabolic and chemical processes and by some subtle transmutation from physical to mental, furnish it, through the medium of the eye, with a perception of surroundings external to itself.

When we say that we see an object we scientifically mean that we receive from it radiations of such wave-lengths as to produce retinal stimulation. If it is a self-luminous body, such as the sun, we receive light from it *per se;* if it is not, the object merely passes on or reflects the light which it receives from something else. It is obvious that in neither case do we see the thing itself; we are conscious only of a

certain sense impression derived from it. The nature of this sense impression, the manner and the way in which it is developed from a physical stimulation of the retina, whether the impulses be electrical, chemical or mechanical in nature or origin, and the transition steps from stimulation to mental interpretation, are problems which are engaging the attention of physiologists, anatomists and psychologists. Certain it is that we are able to trace out the physical, anatomical and physiological processes involved in placing upon the retina, in accurate focus, the image of an object, situated between the two extremes technically known as the punctum remotum and the punctum proximum. These processes, in fact, in their mechanism and results, constitute the essentials of physiologic optics: we have to deal with the human eye as an optical instrument made of living parts, and with a pair of eyes as two such instruments possessed of duction and version powers through the agency of the extra-ocular muscles working, under normal conditions, in harmony to afford binocular single vision. *Physiologic optics* is a science which touches the highest philosophic problems of the human mind on the one hand, and, on the other, keeps in most intimate contact with the practical work of the practitioner upon, and student of, the eye who, in his work of refraction, must be guided by its fundamental principles.

It was with propriety, then, that the versatile von Helmholtz divided his classic *Handbuch der Physiologischen Optik* into three general portions;—(1) the passage of light into the eye or the dioptrics of the eye, (2) the functions of the retina and (3) the interpretations and appreciation of the outer world through the sense of sight. We shall, in turn, follow some such general classification of the subject-matter to be presented; various opinions, theories and practices which have been accorded the partial or complete acceptance of the scientific world will be given and briefly discussed.

Let us devote our attention first of all to a consideration of *ocular dioptrics;* a topic, by the way, too often slighted by the student and practitioner either because of the lack of fundamental mathematical and optical training or passed over by them in the ever prevalent attempt to grasp in a mechanical way the so-called "practical" results and conclusions to the exclusion of a thorough understanding of the "why and wherefore."

PART ONE

OCULAR OPTICS

I. REFRACTION AT CURVED SURFACES WITH APPLICATIONS TO OCULAR CALCULATIONS

1. Many optical phenomena, among them those which have been found to have most extensive and practical applications, occur in conformity to the following fundamental laws:—

(1) The law of *rectilinear propagation* of light.

(2) The law of *reflection:* this states that when regular reflection takes place the angles of incidence and reflection are equal and both lie in the same plane.

(3) The law of *refraction:* a constant ratio exists between the sines of the angles of incidence and refraction; this ratio is governed solely by the relative optical density of the two media and is known as the index of refraction of the body, for any given or specified wave-length, with respect to the surrounding medium. This is mathematically expressed as

$$\frac{\sin i}{\sin r} = n$$

in which "*i*" and "*r*" represent the angles of incidence and refraction respectively and "n" the index of refraction.

(4) The law of the *independence* of the *different portions of a beam of light.*

These four fundamental experimental facts as to the direction of rays of light are comprehended in a general way in a single law often referred to as the principle of least path or *Fermat's principle of least time.* If a ray of light passes from a point *A* to a point *B* and suffers any number of reflections and refractions, then the sum of the products of the index of refraction (n) of each medium multiplied by the distance traversed (l) in it differs from a like sum for all other paths which are infinitely close to it by terms of the second or higher order; i. e., the variation in the total paths, optically considered, approaches zero. This principle finds frequent and important application in geometrical optics. The four fundamental laws above enumerated relate only to geometrical determinations of the propagation of light and constitute, therefore, a sufficient basis for geometrical optics. We shall assume their validity and proceed to use them in the deductions of ocular constants and data.

2. In order to derive the general relations existing between object distance, (f_1), image distance, (f_2), and the radius of curvature (r), let us take a transparent body, such as glass, having an index of refraction (n_2) and a curved surface *DA* with its center at *C*. Any ray of light, such as *OA* (Fig. 1), directed toward *C*, is normal at the point of incidence *A* and passes into the second medium without deviation. A ray, *OD*, which is not normal to the surface but which makes an angle of incidence $ODM = i$ with the normal *DC* (which is also the radius of curvature when the curve *DA* is a portion of a sphere) will, after refraction, proceed in accordance with the laws of refraction, in the direction *DI*, since a small portion of the curved surface at *D* may be considered plane. In geometrical optics there must be two known geometrical paths of light rays emanating from or toward a point before either the object or image can be located. The rays *OD*

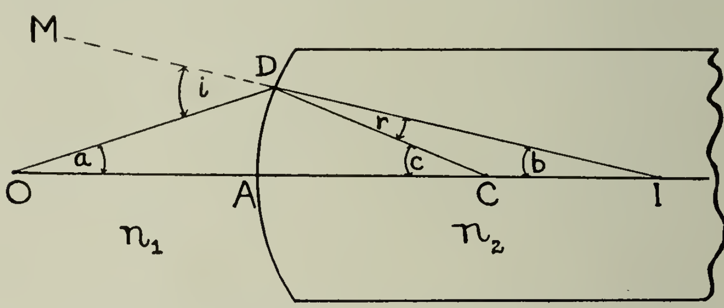


Fig. 1.—Illustrating the Refraction at a Curved Surface Separating Media of Different Optical Indices.

and *OA* intersecting at *O* give a geometrical object; the rays *DI* and *AI* upon intersection at *I* give an image point. The line *AOI*, which is perpendicular to the refracting surface and passes through the center of curvature *C* and the principal focus, is the principal axis. Let *O*, then, be any object point on the axis of a single refracting surface separating media of indices n_1 and n_2, and let *I* be its image formed by refraction at the surface *AD*. Let the angle of incidence $ODM = i$, the angle of refraction $IDC = r$ and the angles $DOA = a$, $DCA = c$ and $DIA = b$.

Then, (1) $n_1 \sin i = n_2 \sin r$. But $i = a + c$ and $r = c - b$.

Hence (2) $n_1 \sin (a + c) = n_2 \sin (c - b)$. If the incident light be considered small apertured and axial, then the angles *a*, *b* and *c* will be small and we can write with sufficient accuracy,

$$(3) \quad n_1 (\sin a + \sin b) = n_2 (\sin c - \sin b)$$

since $\sin (a + b)$, for example, is trigonometrically equal to

sin a · cos b + sin b · cos a, which expression, in turn, becomes equal to *sin a* + *sin b* when the angles under consideration are small, since the cosines of small angles approximate a value of unity.

Let OA = f_1; AI = f_2 and CA = r, the radius of curvature. Then

$$\sin a = \frac{DA}{OD} = \frac{DA}{OA} = \frac{DA}{f_1}$$

$$\sin b = \frac{DA}{DI} = \frac{DA}{AI} = \frac{DA}{f_2}$$

$$\sin c = \frac{DA}{DC} = \frac{DA}{r}$$

A substitution of these values in the preceding equation gives

$$(4) \quad n_1 \left(\frac{1}{f_1} + \frac{1}{r}\right) = n_2 \left(\frac{1}{r} - \frac{1}{f_2}\right)$$

or

$$(5) \quad \frac{n_1}{f_1} + \frac{n_2}{f_2} = \frac{n_2 - n_1}{r}$$

This is without doubt the most important and fundamental equation in optics from the ocular standpoint, as will be shown in its applications in these pages. It is to be noted that this equation definitely establishes a relationship between five optical quantities; it is the equation of *conjugate foci.* Likewise, it will be noted that f_1, f_2 and r are all treated as geometrically positive quantities: when object, image and center of curvature are situated as in the accompanying diagram or when object and image are interchanged in positions we shall assume this convention of signs. Frequently all quantities are considered positive when measured from left to right, and negative when measured from right to left, the pole *A* being the point from which all measurements are made. Other conventions as to algebraic signs are also in vogue and the reader is often bewildered and at a loss because of them and because of the lack of uniformity of symbolic optical nomenclature.

The refractive power of a curved surface depends, then, upon its

curvature and the relative refractive index of the two bounding media. The focal length depends upon the refractive power.

3. In Fig. 2 (*a* and *b*), *RR* is the principal or refracting plane at which all refraction is assumed, to within second order effects, to occur. The point *C*, which is the center of curvature of the surface *DA*, is also the optical center (or single nodal point of this system) since any ray which passes through this point suffers no refraction or lateral deviation. In Fig. 2(a) the incident light is parallel to the

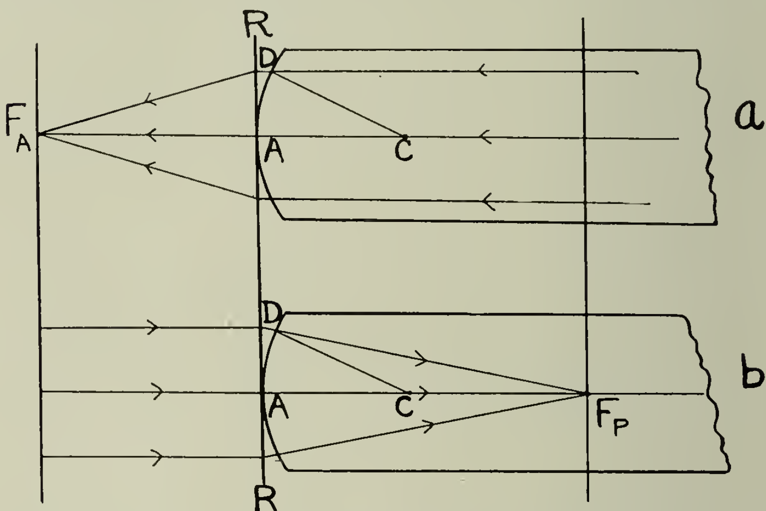


Fig. 2.—Illustrating the Refraction of Parallel Rays by a Curved Surface giving: (a) Anterior Focus, (b) Posterior Focus.

principal axis in the denser medium of index n_2 and upon emergence into the less dense medium, index n_1, is refracted so as to meet at the point F_A. F_AA is the *anterior focal distance.* In a similar manner, parallel light entering from the rarer medium will be focused in the denser medium at F_P. F_PA represents the *posterior focal distance.* F_A and F_P are the anterior and posterior focal points respectively.

If, then, the incident light in the rarer medium be regarded as parallel and hence coming from infinity, the term $\frac{n_1}{f_1}$ becomes zero and, therefore, the general law of conjugate foci which reads

$$\frac{n_1}{f_1} + \frac{n_2}{f_2} = \frac{n_2 - n_1}{r}$$

becomes

$$\frac{n_2}{f_2} = \frac{n_2 - n_1}{r}$$

and the *posterior principal focal length*

$$F_P = \frac{n_2 r}{n_2 - n_1} = \frac{n_1 r}{n_2 - n_1} + r.$$

In like manner, when parallel light is passing from the denser to the rarer medium, $\frac{n_2}{f_2}$ becomes zero and

$$F_A = \frac{n_1 r}{n_2 - n_1}$$

When one of the media is air, $n_1 = 1$ and the above equations simplify into

$$F_A = \frac{r}{n - 1}$$

$$\text{and} \quad F_P = \frac{nr}{n - 1} = \frac{r}{n - 1} + r$$

We note that $F_P = F_A + r = n\,F_A$ and draw from the preceding discussion the following conclusions:—

(a) The difference between the focal distances is equal to the radius of curvature.

(b) The distance of the center of curvature from the posterior focus is equal to the anterior distance and the distance of the center from the anterior focus is equal to the posterior focal distance.

(c) The ratio between the focal distances is equal to the ratio between the indices of the corresponding media.

4. To construct the image of a point removed from the principal axis, we can geometrically proceed as shown in Fig. 3.

(a) A ray, *MD*, parallel to the axis *NC:* it is refracted through the posterior focal point F_P.

(b) A ray, *MC*, proceeding toward the center of curvature or optical center *C:* it is not displaced upon refraction but passes straight through.

(e) A ray, MF_A, passing through the anterior focus: it is parallel, after refraction, to the axis.

From the similarity of the triangles MNF_A and F_ARX we have the ratio

$$\frac{NF_A}{F_AX} = \frac{MN}{RX} = \frac{MN}{M_1N_1}$$

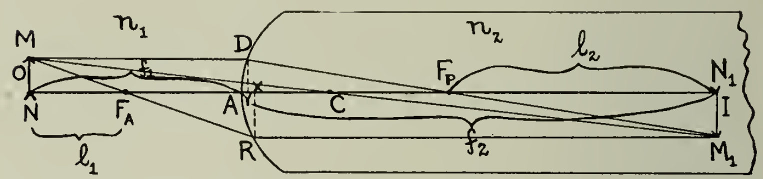


Fig. 3.—The Geometrical Construction of the Image of an Object as Produced by a Single Refracting Surface.

or $\dfrac{l_1}{F_A} = \dfrac{O}{I}$ and from the similarity of the triangles DYF_P and $F_PM_1N_1$ the ratio $\dfrac{F_P}{l_2} = \dfrac{O}{I}$. Hence we deduce the general formula

$$l_1\, l_2 = F_A\, F_P$$

and by substitution therein of the values $l_1 = f_1 - F_A$ and $l_2 = f_2 - F_P$, we obtain the equation

$$\frac{F_A}{f_1} + \frac{F_P}{f_2} = 1$$

Other expressions for the magnification and size of the object or image when the size of one of these is known may be deduced from the similarity of triangles in Figure 3. Two magnification ratios, other than those just developed, are

$$(1)\ M = \frac{O}{I} = \frac{f_1 + r}{f_2 - r},$$

i. e., whatever may be the distance of the object, its size and that of the image are in the same ratio as their respective distances from the center of curvature, and

$$(2)\quad M = \frac{O}{I} = \frac{f_1 n_2}{f_2 n_1}.$$

5. It will subsequently be shown that the complex optical system of the eye with its different refractive media having slightly different indices of refraction may be approximately represented by a single simple system consisting of a refractive medium of index, $n = \frac{4}{3}$, bounded by a convex spherical surface, representing the cornea, having a radius of curvature of 5 millimeters. If we assume such a "reduced eye," we can calculate the positions of the anterior and posterior focal points, the sizes of retinal images, the apparent size and depth of the pupil and the amount of axial change corresponding to each diopter of axial ametropia.

When $n_1 = 1$, $n_2 = \frac{4}{3}$ and $r = 5$ mms., an *emmetropic reduced eye,* with passive fixation at infinity, gives

$$F_A = \frac{r}{n_2 - n_1} = \frac{5}{\frac{4}{3} - 1} = 15 \text{ mm.}$$

$$\text{and } F_P = \frac{n_2 r}{n_2 - n_1} = \frac{\frac{4}{3} \times 5}{\frac{4}{3} - 1} = 20 \text{ mm.}$$

The second or posterior principal focus therefore lies 20 mms. behind the refracting plane and the anterior focus is 15 mms. in front of it. This anterior focal distance of 13 to 15 millimeters is commonly assumed in practice and is of importance since any lens placed in the first focal plane of an eye produces no change in the size of the image formed unless accommodation occurs, but simply shifts the image backward or forward as the case may be.

6. In order to calculate the size of a retinal image under certain conditions of distance and size of object, let us determine the size of such an image for an emmetropic reduced eye viewing a letter *I* in the normal 20-foot line. This letter, which subtends at the nodal point of an assumed normal eye an angle of 5 minutes, is 0.35 inch or 8.7 mms. in height. Then

$$\frac{\text{Object size}}{\text{Image size}} = \frac{8.7 \text{ mms.}}{\text{Image}} = \frac{f_1 + r}{f_2 - r} = \frac{6100 + 5}{15}$$

or $6105 \times \text{Image} = 131$, or the size of the image is 0.023 mm. It will be noted, in passing, that to all practical intents and purposes the

quantity $f_1 + r$ may be regarded as equal to f_1 whenever the distances of the object from the optical center are large in comparison with the value of the radius of curvature. Likewise, the numerical value of the retinal image as calculated above, 0.023 mm., is a constant quantity whenever the various letters of the visual acuity chart, calculated upon a 5′ basis, are viewed by an emmetropic eye at the distance specified upon the chart. The ratio of object size to size of retinal image for a normal eye exerting no accommodation is approximately 400 to 1.

7. The apparent size and position of the pupil of the eye may be calculated by a use of the law of refraction at curved surfaces and the magnification formulæ. By experimentation the average radius of curvature of the human cornea has been found to be about 7.8 mms. and its index of refraction approximately 1.33; the anterior surface of the crystalline lens is 3.54 mms. from the anterior surface of the cornea. For purposes of the present calculation let us assume $r = 8$ mms., $n_1 = 1.33$, $n_2 = 1$ and let the pupil of the eye serve as the object at 3.60 mms. behind the surface of the anterior surface of the cornea, and let it be 2 mms. in diameter; we desire to find its apparent size and position. In this case n_1 is the denser medium containing the object and the cornea is concave toward it. Hence

$$\frac{n_2}{f_2} + \frac{n_1}{f_1} = \frac{n_2 - n_1}{r}$$

becomes $$\frac{1}{f_2} = \frac{1 - 1.33}{-8} - \frac{1.33}{3.6} = -\frac{1}{3.05}$$

Hence f_2, i. e., the image position, is virtual and 3.05 mms. behind the surface. Its size is

$$I = \frac{2 \times 3.05 \times 1.33}{3.6} = 2.25 \text{ mms.}$$

Hence the pupil appears larger and nearer the anterior corneal surface than it actually is.

8. The statement is frequently found in treatises on visual optics and ophthalmology that an axial change, whether it be an increase or a decrease in the depth of the eye from cornea to macula, of one millimeter approximately represents an ametropia of three diopters. This statement is sufficiently accurate for practical purposes; it can be shown, however, that this ratio of 1 mm. change in depth to 3 D of error is not exact, that its value varies slightly by different methods

of computation, that its value is not the same for myopic as for hyperopic changes of equal amounts and that this ratio does not remain constant as the axial dioptric error increases. The application of the general law of refraction at curved surfaces furnishes a clear and concise proof. Assume a condition of axial myopia of 1 D. The punctum remotum, f_1, or distance of distinct vision, will therefore be 100 cms. We desire to find its conjugate, f_2, which in this case is to lie upon the retina. Since $n_1 = 1$, $n_2 = 4/3$ and $r = 5$ mm. (employing the Donders' reduced eye) we have, upon substitution in the general equation of refraction at curved surfaces,

$$\frac{1}{1000} + \frac{4/3}{f_2} = \frac{4/3 - 1}{5}.$$

Simplifying and solving, we have

$$591\ f_2 = 1200$$
$$f_2 = 20.3 + \text{mms.}$$

By reference to the calculation made for an emmetropic reduced eye in one of the preceding paragraphs, the reader will find that the value of f_2 is 20 mms. The conclusion therefore follows that an axial change of 0.33 mm. represents an axial ametropic error of 1 diopter. In the particular case of myopia assumed for illustrative purposes, a — 1 D lens in the first focal plane of the eye would extend the punctum remotum from the one meter point back to infinity and place the image of an object situated at infinity upon the retina rather than allowing it to fall in the vitreous. It is, of course, to be clearly understood that such ametropic errors may be due to corneal, lenticular or indicial abnormalities: they have been treated and discussed thus far as "equivalent" axial errors only.

To illustrate the application of these principles to a condition of axial hypermetropia, let us assume a "short" eye 19 millimeters in depth. Taking the radius of curvature as 5 mms. and the index of refraction as $4/3$, it is necessary to calculate first of all the focal distance, f_1, conjugate to the known posterior focal distance $f_2 = 19$ mms. The expression is

$$\frac{1}{f_1} + \frac{4/3}{19} = \frac{4/3 - 1}{5}$$

$$\text{or } \frac{1}{f_1} = \frac{1}{15} - \frac{4}{57} = -\frac{3}{855}$$

Hence $f_1 = -288$ mms.

The negative sign is of significance, for it indicates that the anterior focal point is on the same side of the refracting surface as the posterior focal point, indicating, therefore, a virtual point back of the retina. This is in accord with the commonly known principle that only light converging toward the eye can be brought to a focus upon the retina of an hyperopic eye not exerting its accommodation. These conditions are diagrammed in Fig. 4. F_P and F_A are conjugate foci; $AF_P = 19$ mms. and F_A, by calculation, is -288 mms. This distance, 288 mms., in dioptric equivalent is practically 3.50 D; this eye has 19 mms. instead of 20 mms. as its posterior focal length; we therefore

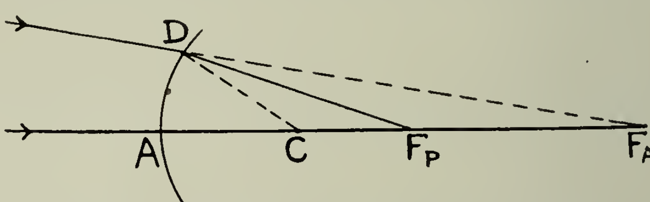


Fig. 4.—Illustrative of the Optical Conditions Existing in a Hyperopic Eye as to Conjugacy of Foci.

conclude that 1 mm. decrease in the depth of the normal eye, representing hypermetropia, indicates an axial error of 3.5 D.

The practitioner is herewith also furnished the basis for calculations which may be of diagnostic value in conjunction with ophthalmoscopic examinations. We do not refer to the use of the ophthalmoscope as an instrument for the measurement of refractive errors, but rather to its employment in determining differences in level between the edge or ring of the optic disc and the center of the cup in, for example, physiologic cup, glaucoma and choked disc. The difference in the lens quantity which the observer must turn up in his instrument in order to, let us say, clearly see in turn the edge and the center of the disc, gives a measurement of fair accuracy upon the relative elevation or depression; for instance, edge of disc -2 D, center -8 D, difference -6 D, indicating a maximum cup depth or difference in fundus level of about 2 mms.

II. THE GAUSS EQUATION AND ITS APPLICATION TO THE DIOPTRIC SYSTEM OF THE EYE

9. The theory of lenses is simple if the thickness is negligible. The axis of such a lens is designated as the straight line which joins the two centers of the surfaces, and the optic center is a point on this line such that any ray passing through it suffers no angular deviation

or lateral displacement. In the case of bi-convex and bi-concave lenses the optical center is at the geometrical center. The general formula for the focal length, $F_A = F_P$, of a thin lens in terms of the index (n) and the radii of curvature (r_1 and r_2) may be derived from a double application of the methods of procedure and mathematical processes considered under refraction at curved surfaces and is of the form

$$\frac{1}{F_A} = \frac{1}{F_P} = (n - 1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

If the lenses are not sufficiently thin so that their thicknesses may be neglected, nor placed so near together that their distances apart can be overlooked, the position and size of the image may still be found by construction or calculation; one must construct or calculate first of all the image formed by the first surface, which image in turn serves as the object for the second surface and so on. By the aid of the Gauss equation every optical system can be so simplified that all problems of conjugacy of foci and other optical data can be solved by formulæ applicable to single thin lenses. The system must, however, be centered, which is to say that all the centers of the surfaces must lie on the axis, the pencils of light passing through the various members of this system must be axial and small, hence aberration is neglected.

According to the Gaussian theory every optical system has six cardinal points, to wit:—

One anterior focus, F_A.
One posterior focus, F_B.
Two principal points, H_1 and H_2.
Two nodal points, N_1 and N_2.

To illustrate the course of light in a compound optical system and to aid in the definitions of principal and nodal points, we cannot do better than to take the case of the eye itself and presume at this point the correctness of some of the conclusions to which we shall ultimately arrive. The dioptric system of the eye consists, as shown in Fig. 5, of three refracting systems; the cornea S_1, the anterior surface of the lens S_2, the posterior surface of the lens S_3, separating four media of indices n_1 (air), n_2 (aqueous), n_3 (lens) and n_4 (vitreous).

The anterior focal distance, $F_A = H_1 F_A$, is the distance from the first principal point to the anterior focus; it is also equal to the distance of the second nodal point from the posterior focus, $N_2 F_P$.

The posterior focal distance, $F_P = H_2 F_P$, is the distance from the second principal point to the posterior focus; it is also equal to the distance of the anterior focus from the first nodal point, $F_A N_1$.

Rays in media n_1 parallel to the principal axis meet after refraction in medium n_4 at the point F_P.

Rays diverging from F_A are, after refraction, parallel to the principal axis.

A ray directed toward the first principal point, H_1, appears, after refraction, to proceed from the second, but the direction after refraction is not parallel to its original course.

A ray directed to the second principal point, appears, after refraction, to proceed from the second. The two principal points are images of each other.

A ray directed to the first nodal point, N_1, after refraction appears to come from the second and its direction is parallel to its original

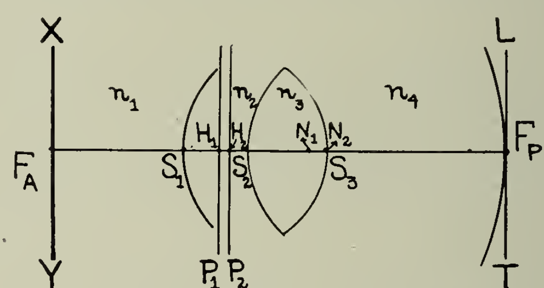


Fig. 5.—The Six Cardinal Points and Dioptric Media of the Eye.

course. A ray directed to the second appears after refraction to come from the first nodal point. In the case of a single refracting surface a ray directed to its nodal point passes through without deviation; but in a compound system, where there are two nodal points, a ray must be directed to the first in order to appear to come from the second. The two nodal points are images of each other.

The distance which separates the two principal points is equal to that which separates the two nodal points, or $H_1 H_2 = N_1 N_2$ (Fig. 5).

Three important relations, therefore, exist in such a compound dioptric system:—

(a) $H_1 F_A = N_2 F_P$

(b) $H_2 F_P = N_1 F_A$

(c) $H_1 H_2 = N_1 N_2$

10. Provided, then, the six cardinal points are known, the most complicated system can be reduced to the simplicity of a single lens. Knowing these six points, the image of a given point or object, *XY*,

Fig. 6, can be found by construction choosing any two of the three following rays:—

(1) The ray XA, parallel to the axis, must cut the second principal plane at D at a distance from the axis equal to AH_1 and it must pass through F_P. It takes the direction DX_1.

(2) The ray XB, passing through the anterior focal point F_A, must after refraction be parallel to the axis YY_1: it will take the direction BX_1.

(3) The ray XN_1, directed toward the first nodal point, takes after refraction the direction N_2X_1 parallel to its original direction.

11. In Fig. 6, let $YF_A = l_1$, $H_1F_A = F_A$, $H_1Y = f_1$, $Y_1F_P = l_2$, $H_2F_P = F_P$ and $H_2Y_1 = f_2$. The triangles XYF_A and BH_1F_A on the

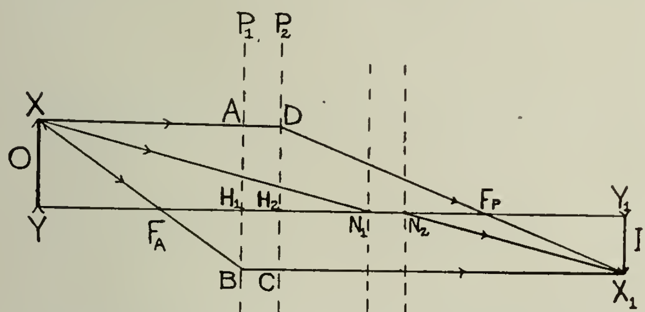


Fig. 6.—Illustrating Image Formation when the Six Cardinal Points are Known, Whereby a Complicated System can be Reduced to a Single Lens Equivalent.

one side and the triangles DH_2F_P and $Y_1X_1F_P$ on the other side being similar give the relation

$$\frac{\text{Image}}{\text{Object}} = \frac{O}{I} = \frac{l_1}{F_A} = \frac{F_P}{l_2}$$

We have then, as before, the relation $l_1l_2 = F_AF_P$ and we can deduce therefrom the general formula

$$\frac{F_A}{f_1} + \frac{F_P}{f_2} = 1.$$

12. The formulæ which follow are deduced for the purpose of giving the general method and the outline of the mathematical procedure involved in the Gauss equation; the applications to the dioptric system of the eye will then follow. In order to keep the formulæ as symmetrical as possible and to avoid errors in algebraic signs, the

following conventions will be observed: (a) all distances measured to the left of a surface are negative and to the right, positive; (b) all thicknesses are considered negative and when actual numerical values are substituted the minus signs must be employed. Let n_1 be the refractive index of the medium surrounding a lens, n_2 that of the lens, t its axial thickness and r_1 and r_2 the radii of curvature of the first and second surfaces of the lens respectively. Let u be the object distance, v_1 the image distance due to the refraction at the first surface and v the final image distance after refraction at the second surface. The fundamental equation for the refraction at the first curved surface assumes the form

$$\frac{n_2}{v_1} - \frac{n_1}{u} = \frac{n_2 - n_1}{r_1}$$

In order to simplify the formula, $\frac{n_2 - n_1}{r_1}$ is replaced by F_1 and $\frac{n_2}{v_1}$ and $\frac{n_1}{u}$ are replaced by their so-called *reduced* expressions $\frac{1}{v_1}$ and $\frac{1}{u}$. Similarly in the expression for the refraction at the second lenticular surface the expression $\frac{n_1 - n_2}{r_2}$ will be put equal to F_2, and $\frac{n_1}{v}$ and t, the lens thickness, will be given their reduced values, $\frac{1}{v}$ and $\frac{t}{n}$, where n represents the index of the medium in which the quantity is measured. Ultimately, of course, the numerical values obtained by means of these reduced equations must be multiplied by the proper quantities in order to literally "undo" these simplifications. The "reduced" fundamental equation becomes

$$\frac{1}{v_1} - \frac{1}{u} = F_1$$

$$\text{whence} \quad v_1 = \frac{1}{F_1 + \frac{1}{u}} \quad \text{.........................} (1)$$

The expression connecting v_1 (the image formed by the first refraction which, in turn, serves as the object for the second refraction) and v, the final image is

$$\frac{n_1}{v} - \frac{n_2}{v_1 + t} = \frac{n_1 - n_2}{r_2}$$

or as a reduced expression $\frac{1}{v} - \frac{1}{v_1 + t} = F_2$, whence

$$v = \cfrac{1}{F_2 + \cfrac{1}{v_1 + t}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

By a substitution of the value of v_1 (equation 1) in equation 2 we obtain

$$v = \cfrac{1}{F_2 + \cfrac{1}{t + \cfrac{1}{F_1 + \cfrac{1}{u}}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

This continued fraction, when worked out, gives

$$v = \frac{u\,(F_1t + 1) + t}{u\,(F_1F_2t + F_1 + F_2) + F_2t + 1} \quad \ldots\ldots\ldots\ldots\ldots (4)$$

This may, for brevity's sake, be written

$$v = \frac{Bu + D}{Au + C} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where
$$\begin{aligned} A &= F_1F_2t + F_1 + F_2 \\ B &= F_1t + 1 \\ C &= F_2t + 1 \\ D &= t \end{aligned}$$

Equation (5) correlates u and v when both are finite. When u is at infinity, then the focal length measured from the second surface is

$$v = \frac{B}{A} \qquad (6)$$

This value of v in equation (6) is known as the *back focal distance* measured from the pole of the second surface. When v is infinite, then in equation (5) Au + C must equal zero and

$$u = -\frac{C}{A} \qquad (7)$$

This gives the value of the focal length measured from the pole of the first surface.

In order to find the positions of H_1 and H_2, the equivalent points, and N_1 and N_2, the nodal points, it is necessary to derive an expres-

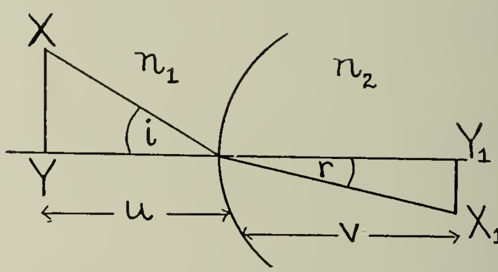


Fig. 7.—Graphically Illustrative of the Magnification Produced by a Refracting Surface.

sion for the total magnification, *M*, produced by the lens system. If m_1 represents the magnification due to the first surface and m_2 that produced by the second similar surface, then $M = m_1 \times m_2$.

13. In Fig. 7 let XY be an object in front of the first surface and X_1Y_1 its corresponding image. The angles "i" and "r" represent incidence and refraction respectively.

Then $m_1 = \frac{X_1Y_1}{XY}$. When the angles are small $\sin i = \frac{XY}{u}$ and $\sin r = \frac{X_1Y_1}{v_1}$ and $\frac{\sin r}{\sin i} = \frac{n_1}{n_2}$ or $m_1 = \frac{n_1 v_1}{n_2 u}$. When we express this ratio in reduced quantities we have $m_1 = \frac{v_1}{u}$. In a like manner the

magnification, m_2, of the second surface is $m_2 = \dfrac{v}{v_1 + t}$ and $M = m_1 \times$

$$m_2 = \frac{v_1}{u} \times \frac{v}{v_1 + t}.$$

From equation (1) $\dfrac{v_1}{u} = \dfrac{1}{F_1u + 1}$, and from equations (1) and (2)

$$\text{we have } \frac{v}{v_1 + t} = \frac{1}{F_2\left(\dfrac{u}{F_1u + 1} + t\right) + 1}$$

$$\text{Hence } M = \frac{1}{F_1u + 1} \times \frac{F_1u + 1}{u(F_1F_2t + F_1F_2) + F_2t + 1}$$

$$= \frac{1}{u(F_1F_2t + F_1 + F_2) + F_2t + 1}$$

$$= \frac{1}{Au + C} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

in terms of our previous notation.

14. If now the virtual image and object be equal in size, the magnification will be $+1$. The planes of unit virtual magnification for thick lenses and lens systems lie in the equivalent or principal planes. If such were possible and one could place a small object in one plane, then its virtual image, identical in all points to the object, would be situated in the other. Hence $Au + C = 1$ and

$$u = H_1 = \frac{1 - C}{A} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

measured from the first surface.

Equation (5) reads $v = \dfrac{Bu + D}{Au + C}$ and by substitution of the value

of u from equation (9) in equation (5) there is obtained

$$v = H_2 = \frac{B - B \times C + A \times D}{A}$$

$$= \frac{B - 1}{A} \qquad \text{.......................... (10)}$$

since $(A \times D) - (B \times C) = 1$. The distance $v = H_2$ is measured from the second surface.

The values of u and v from equations (9) and (10) must be added to those of u and v in equation (5) in order to find the equivalent focal distances, since equivalent focal distances must always be measured from the equivalent planes to the points representing the back focal distances. Hence

$$v + \frac{B - 1}{A} = \frac{B\,[u + (1 - C)/A] + D}{A\,[u + (1 - C)/A] + B}$$

which reduces to $A = \frac{1}{v} - \frac{1}{u}$ .... (11)

This expression, the reader will observe, is precisely similar in form to the general thin lens formula involving object and image distances and principal focal lengths.

When u is infinite, $v = \frac{1}{A}$ and when v is infinite, $u = -\frac{1}{A}$. These are, of course, reduced expressions and in obtaining numerical results they must be multiplied by the proper index of refraction in every case.

15. We are now in a position to apply the Gaussian method to the case of the eye having three surfaces, S_1, S_2 and S_3 (see Fig. 5), with thicknesses t_2 and t_4, with the following data:—

r_1 (cornea) $= 8$ mms.

r_3 (anterior surface of the crystalline) $= 10$ mms.

r_5 (posterior surface of the crystalline) $= 6$ mms.

t_2 (thickness of aqueous) $= 3.6$ mms.

t_4 (thickness of crystalline lens) $= 3.6$ mms.

$n_1 = \text{air} = 1.$
$n_2 = \text{aqueous} = 1.333.$
$n_3 = \text{lens} = 1.45.$
$n_4 = \text{vitreous} = 1.333.$

Let F_1, F_3 and F_5 represent the reduced focal lengths of the three surfaces S_1, S_2 and S_3. Then

$$F_1 = \frac{n_2 - n_1}{r_1} = \frac{1.333 - 1}{8} = 0.0416 \text{ mm.}$$

$$F_3 = \frac{n_3 - n_2}{r_3} = \frac{1.45 - 1.333}{10} = 0.0117 \text{ mm.}$$

$$F_5 = \frac{n_4 - n_3}{r_5} = \frac{1.333 - 1.45}{-6} = 0.0195 \text{ mm.}$$

The reduced values of t_2 and t_4 are:

$$t_2 = \frac{-3.6}{1.333} = -2.7007 \text{ mm.}$$

$$t_4 = \frac{-3.6}{1.45} = -2.4830 \text{ mm.}$$

Writing an equation for v, similar to equation (3), in the form of a continued fraction and side by side with it the expression with numerical values substituted, we have:—

$$v = \cfrac{1}{F_5 + \cfrac{1}{t_4 + \cfrac{1}{F_3 + \cfrac{1}{t_2 + \cfrac{1}{F_1 + \cfrac{1}{u}}}}}} \qquad v = \cfrac{1}{0.0195 + \cfrac{1}{-2.4828 + \cfrac{1}{0.0117 + \cfrac{1}{-2.7007 + \cfrac{1}{0.0416 + \cfrac{1}{u}}}}}}$$

This equation when worked out gives

$$v = \frac{0.7587u - 5.105}{0.0668u + 0.869} = \frac{Bu + D}{Au + C};$$

whence $A = 0.0668$ $\quad C = 0.869$
$B = 0.7587$ $\quad D = -5.105$

Finally,

$$F_A = \text{anterior focus} = \frac{-n_1}{A} = \frac{-1}{0.0668} = -15 \text{ mms.}$$

$$F_P = \text{posterior focus} = \frac{n_4}{A} = \frac{1.333}{0.0668} = +20 \text{ mms.}$$

$$H_1 = \text{first equivalent point} = \frac{n_1(1 - C)}{A} = \frac{0.1311}{0.0668}$$

$= 1.96$ mm. from r_1 toward the lens.

$$H_2 = \text{second equivalent point} = \frac{n_4(B - 1)}{A} = \frac{-0.3128}{0.0668}$$

$= -4.81$ mms. from r_5, or $t_2 + t_4 - 4.81 = 7.2 - 4.81 = 2.39$ mms. from r_1 toward the lens.

The distance of the nodal points from the equivalent points is always equal to the difference between the anterior and the posterior focal lengths; hence $N_1 = F_P - F_A$ from H_1 and $N_2 = F_P - F_A$ from H_2. The value of $F_P - F_A$, algebraically considered as representing two linear dimensions, is $20 - 15 = 5$ mms. Therefore,

N_1 = first nodal point $= 5 + 1.96 = 6.96$ mms. from r_1.
N_2 = second nodal point $= 5 + 2.39 = 7.39$ mms. from r_1.

In brief tabulation, the six cardinal points of the eye are situated with respect to the cornea as follows:—

$F_A = 13.05$	mms. from cornea	$H_1 = 1.95$ mms.	$N_1 = 6.95$ mms.
$= 15$	mms. from H_1		
$= 20$	mms. from N_1		
$F_P = 22.38$	mms. from cornea	$H_2 = 2.38$ mms.	$N_2 = 7.38$ mms.
$= 20$	mms. from H_2		
$= 15$	mms. from N_2		

16. Gauss's theory supposes that the aperture of the system is very small. This is not true in the case of the eye, and, according to Tscherning, "many errors committed in questions of ocular refraction appear to be due to the fact that we do not sufficiently take into account the large aperture of the system." In optical instruments an aperture of over ten degrees is not considered acceptable. If we assume that the pupil of the eye has a diameter of four millimeters, the aperture of the cornea would be twenty degrees. Ordinarily under normal conditions the pupillary diameter is as great as five or six millimeters. We have shown in a preceding paragraph that the pupil as seen through the cornea has neither its real position nor its true size: it appears moved forward approximately 0.5 mm. and enlarged on account of the refraction through the cornea by nearly the same amount. We view, then, a virtual image of the iris and of the pupil; they are the apparent iris and the apparent pupil and are aerial images. Rays in air which are directed toward a point of the apparent pupil are, after refraction by the cornea, directed toward the corresponding point of the real image. The apparent pupil belongs to the incident rays as does also the first principal point or the first nodal point, and the crystalline image of the pupil belongs to the emergent rays. The luminous cone which enters an eye is therefore limited by the apparent pupil; in its course between the cornea and the crystalline it is limited by the real pupil and in the vitreous by the crystalline image of the pupil. Professor Abbe has proposed the names of pupil of entrance and pupil of exit for the images of the diaphragm. The principal planes are each, in turn, the image of the other and the object and image are of the same size and the general formula $\frac{F_A}{f_1} + \frac{F_P}{f_2} = 1$ holds when all measurements are made from the principal points. Calculations could just as well be made from any other pair of points which are images one of the other; the entrance and exit pupils are such, except that object and image are not of the same size. This then is the essential difference and the point of value in this discussion; if an incident ray meets the first principal plane at a distance from the axis equal to x, the emergent ray also cuts the second principal plane at a distance from the axis equal to x. But if the incident ray meets the pupil of entrance at a distance from the axis equal to x, then the emergent ray cuts the plane of the pupil of exit at a distance from the axis which bears the same relation to x as the diameter of the pupil of exit does to that

of the pupil of entrance. If we assume an actual pupillary diameter, or exit pupil, of 4 mms., then the entrance pupil will be about 4.5 mms. and the ratio would be 40/45.

III. THE FUNDAMENTALS OF THICK LENS OPTICS AND THEIR APPLICATIONS TO OCULAR CALCULATIONS

17. The student of physiologic optics, desirous of making detailed ocular calculations as to the various optical constants of the different media of the eye and of computing the combined dioptric system of the eye and an auxiliary lens, will find the following brief presentation of the essentials of thick lens optics of service. We shall proceed to find or to give expressions for the effectivity, the equivalent focal

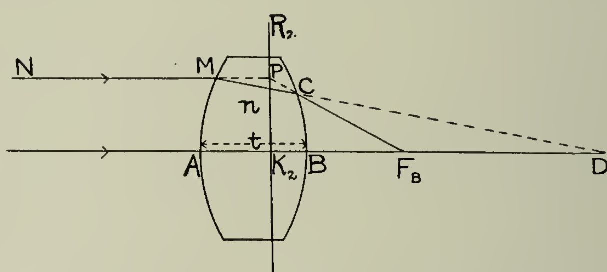


Fig. 8.—Back Focal Length and Equivalent Points of a Thick Lens.

length and the positions of the equivalent points in terms of the radii, thickness and index of the lens. Let

F_E be the equivalent focal length;
K_1 and K_2 be the first and second equivalent points;
T be the distance between K_1 and K_2, or the optical interval;
r_1 and r_2 be the radii of curvature of the surfaces of the lens;
n be the index of the medium;
A and B be the first and second surface points, respectively, on the principal axis.

In Fig. 8, let NM be a parallel ray incident at M; this will be deviated towards the axis by the first surface and would, if not intercepted by the second surface CB, intersect the principal axis AD at D. It is brought, however, by the refraction at the second surface to F_B. Hence, by definition, D is the posterior focus of the first surface, F_B the principal focal point of the lens as a whole and BF_B the back focal length. Project MN and CF_B until they intersect at P; a plane drawn perpendicular to the principal axis through the point P will locate the second equivalent point K_2. All the refraction of light

therefore appears to take place at R_2K_2. The distance K_2F_B is the equivalent focal length, since it is the focal length of the thin lens which, if placed at K_2, would have the same effect as the original thick lens. For parallel light, the image by refraction at the first surface A will be at a distance $AD = F_A$ from this surface, and

$$\frac{n-1}{r_1} = \frac{n}{F_A} \quad \ldots\ldots\ldots\ldots (1)$$

Therefore, the distance of the first image from the second surface will be $AD - AB = F_A - t$. If F_B is the distance of the second, or final, image from the second surface, then

$$\frac{n}{F_A - t} - \frac{1}{F_B} = \frac{n-1}{r_2} = \frac{n}{F_{A_1}} \quad \ldots\ldots\ldots\ldots (2)$$

Hence

$$\frac{1}{F_B} = \frac{n}{F_A - t} + \frac{n}{F_{A_1}}$$

$$= n\left(\frac{t + F_A + F_{A_1}}{F_{A_1}(F_A - t)}\right)$$

or $$F_B = \frac{F_{A_1}(F_A - t)}{n(F_A + F_{A_1} - t)} = BF_B \quad \ldots\ldots\ldots\ldots (3)$$

Substituting values of F_A and F_{A_1} in equation (3) we obtain

$$F_B = \frac{\dfrac{nr_2}{n-1}\left(\dfrac{nr_1}{n-1} - t\right)}{n\left(\dfrac{nr_1}{n-1} + \dfrac{nr_2}{n-1} - t\right)} \quad \ldots\ldots\ldots\ldots (4).$$

This equation, when algebraically simplified, becomes

$$F_B = \frac{nr_1r_2 - tr_2(n-1)}{n(n-1)\left(r_1 + r_2 - \dfrac{t(n-1)}{n}\right)} \quad \ldots\ldots\ldots\ldots (5)$$

$= $ back focal length.

In Fig. 8, the triangles PK_2F_B and CBF_B, considering CB as a straight line, are similar; also the triangles MAD and CBD. Hence

$$\frac{K_2F_B}{BF_B} = \frac{PK_2}{CB} = \frac{MA}{CB} = \frac{AD}{BD} \qquad \ldots\ldots\ldots\ldots (6)$$

K_2F_B is the equivalent focal length which we desire to find; AD is the posterior focal length of the first surface; BD is equal to $AD - AB$ or $AD - t$, and $BF_B = F_B$ is the back focal length. Equation (6) may be written

$$K_2F_B = F_E = BF_B \times \frac{AD}{BD} \qquad \ldots\ldots\ldots\ldots (7)$$

Substituting in this equation the value of BF_B and carrying out the processes involved gives

$$F_E = \frac{r_1r_2}{(n-1)\left(r_1 + r_2 - \frac{t(n-1)}{n}\right)} \qquad \ldots\ldots\ldots\ldots (8)$$

$=$ the equivalent focal length.

The distance of K_2 from the pole B of the second surface is K_2B and can be found from $K_2B = K_2F_B - BF_B = F_E - F_B$, or

$$K_2 = \frac{r_2t}{n\left(r_1 + r_2 - \frac{t(n-1)}{n}\right)} \qquad \ldots\ldots\ldots\ldots (9)$$

and similarly

$$K_1 = \frac{r_1t}{n\left(r_1 + r_2 - \frac{t(n-1)}{n}\right)} \qquad \ldots\ldots\ldots\ldots (10)$$

The optical thickness, T, is the distance between the equivalent points, and is

$$T = t_1 - (K_1 + K_2) \qquad \ldots\ldots\ldots\ldots (11)$$

For purposes of convenience in applying these equations, let

$$Q = r_1 + r_2 - \frac{t(n-1)}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Then

$$F_E = \frac{r_1 r_2}{(n-1)Q} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

$$K_1 = \frac{r_1 t}{n \cdot Q} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

$$K_2 = \frac{r_2 t}{n \cdot Q} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

The application of these formulæ to ocular calculations follows in the succeeding paragraphs.

18. *Schematic eye No. A*

This is calculated for an axial length of 22.2 mms. The data used is as follows (see Fig. 5) :—

r_1 = radius of curvature of cornea, $S_1 = 8$ mms.
r_2 = radius of anterior surface of crystalline, $S_2 = 10$ mms.
r_3 = radius of posterior surface of crystalline, $S_3 = 6$ mms.
Distance S_1S_2 (from cornea to crystalline) $= 3.6$ mms.
$S_2S_3 = t$, the thickness of crystalline $= 3.6$ mms.
$n_1 = 1 \qquad n_2 = 1.333 \qquad n_3 = 1.45 \qquad n_4 = 1.333.$

19. *Optics of the cornea*

$$F_A = \text{anterior focal length} = \frac{n_1 r_1}{n_2 - n_1} = 24 \text{ mms.}$$

$$F_B = \text{posterior focal length} = \frac{n_2 r_1}{n_2 - n_1} = 32 \text{ mms.}$$

$$\frac{F_A}{F_B} = \frac{24}{32} = \frac{1}{1.333} = \frac{3}{4} = \frac{n_1}{n_2}$$

20. *Optics of the crystalline lens*

The index is presumed to be 1.45 and the lens is situated with media on both sides of index practically equal to 1.333. The relative index, n_r, of the crystalline is

$$n_r = \frac{n_3}{n_2} = \frac{1.45}{1.333} = 1.087$$

Equation (12) reads: $Q = r_1 + r_2 - \frac{t(n-1)}{n}$, or $Q = 10 + 6 - 3.6 \times \frac{1.087 - 1}{1.087} = 15.72$ mms.

$$K_1 = \frac{r_1 t}{n_r Q} = \frac{10 \times 3.6}{1.087 \times 15.72} = 2.1 \text{ mms.}$$

$$K_2 = \frac{r_3 t}{n_r Q} = \frac{6 \times 3.6}{1.087 \times 15.72} = 1.26 \text{ mms.}$$

The anterior and posterior focal lengths are equal, since the aqueous and vitreous have the same indices, and will be represented by F_C.

$$F_E = F_C = \frac{r_1 r_2}{(n_r - 1)Q} = \frac{10 \times 6}{0.087 \times 15.72} = 43.86 \text{ mms.}$$

The distance $K_1K_2 = T_C$ of the lens. Hence

$$T_C = 3.6 - (2.1 + 1.26) = 0.24 \text{ mm.}$$

21. *Optics of the combined cornea and crystalline lens*

Having thus considered the optics of the crystalline lens and having deduced mathematical expressions representing the focal length, F_E, of the reduced or thin lens equivalent, the two optical systems A and L (Fig. 9) representing the cornea and crystalline may be combined and the anterior, F_1, and posterior, F_2, focal lengths and other optical constants derived from the formulæ which hold for thin lenses separated by an interval. If we have two thin lenses of focal lengths F_1 and F_2 separated by a distance, d, from center to center, the

following expressions are valid:

F_E = equivalent focal length of combined lenses.

$$= \frac{F_1F_2}{F_1 + F_2 - d} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

K_2 = distance of the second equivalent point from the second lens.

$$= \frac{F_2d}{F_1 + F_2 - d} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

K_1 = distance of the first equivalent point from the first lens.

$$= \frac{F_1d}{F_1 + F_2 - d}$$

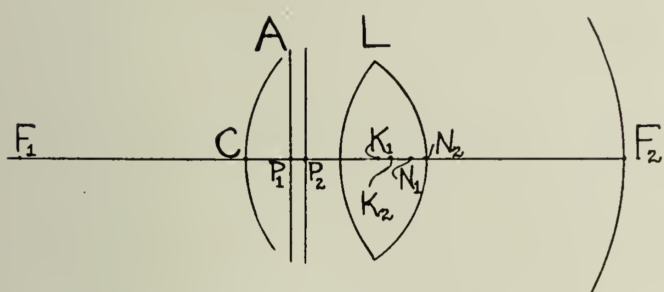


Fig. 9.—The Combined System of the Cornea and the Lens.

and t = equivalent thickness or optic interval.

$$= d - (K_1 + K_2) = \frac{d_2}{F_1 + F_2 - d} \quad \ldots\ldots\ldots\ldots\ldots\ldots (18)$$

The distance K_1 is measured backwards from the first lens and K_2 forward from the second lens; that is, in each case toward the other lens. This means that the algebraic signs attached to these various quantities will be positive if they are to be measured in the directions specified above.

22. Combining the two systems A and L as diagrammed in Fig. 9, the distance between the adjacent principal points of A and L is $CK_1 = d$, or

$$d = CK_1 = 3.6 + 2.1 = 5.7 \text{ mms.}$$

We have previously represented the posterior focal length of the cornea by F_B and the anterior and posterior focal lengths of the crystalline lens, since they are equal, by F_C.

Then $F_B + F_C — d \backsimeq F_1 + F_2 — d$ (equation 16). For the sake of convenience let

$$F_B + F_C - d = Q.$$

Then $Q = 32 + 43.86 - 5.7 = 70.16$ mms. The distance of the first principal point, P_1, behind the cornea is

$$P_1 = \frac{F_A \cdot d}{Q} = \frac{24 \times 5.7}{70.16} = 1.95 \text{ mm.}$$

The distance of the second principal point, P_2, in front of K_2, the second equivalent point of the crystalline, is

$$P_2 = \frac{F_C \cdot d}{Q} = \frac{43.86 \times 5.7}{70.16} = 3.56 \text{ mms.}$$

Hence P_2 lies behind the cornea at a distance

$$CP_2 = 3.6 + 3.6 - (1.26 + 3.56) = 2.38 \text{ mms.}$$

The anterior focal length, F_1, of the whole ocular system is

$$F_1 = \frac{F_A \cdot F_C}{Q} = \frac{24 \times 43.86}{70.16} = 15 \text{ mms.}$$

The posterior focal length, F_2, is

$$F_2 = \frac{F_B \cdot F_C}{Q} = \frac{32 \times 43.86}{70.16} = 20 \text{ mms.}$$

The distance, T, between the principal points is

$$T = P_2 - P_1 = 2.38 - 1.95 = 0.43 \text{ mm.}$$

The nodal points, N_1 and N_2, are found as follows:—the distance N_1P_1 or N_2P_2 is equal to $F_2 - F_1 = 5$ mms. Hence

$$CN_1 = 1.95 + 5 = 6.95 \text{ mms.}$$
$$CN_2 = 2.38 + 5 = 7.38 \text{ mms.}$$

23. *Schematic eye No. (B).*

This will be calculated for an axial length of 24 mms. All the data correspond with schematic eye No. (A) except that n_c, the index of the crystalline, is 1.418. The cornea is as previously calculated.

In the case of the crystalline $n_r = \frac{1.418}{1.333} = 1.0635$. For the crystalline we obtain $K_1 = 2.15$ mms., $K_2 = 1.28$ mms., $F_C = 60$ mms. and $T_C = 0.17$ mm. Combining the two systems, the corneal and lenticular, the approximate values for this eye are

$F_1 = 16.7$ mms.	$P_1 = 1.6$ mm.	$N_1 = 7.16$ mms.
$F_2 = 22.26$ mms.	$P_2 = 1.92$ mm.	$N_2 = 7.48$ mms.
$T = 0.32$ mm.	$F_2 - F_1 = 5.56$ mms.	

24. *The reduced eye*

For convenience in calculations, the eye may be reduced to a single refracting surface so that there is only one refracting surface and medium, the cornea, which is at the ideal refracting plane or principal plane of the schematic eye. This special case has been discussed, with examples, under the caption "Refraction at Curved Surfaces with Applications to Ocular Calculations."

In closing this discussion of the optical system of the eye it is pertinent to add for reference the following table. Other tables, based upon slightly different data, may be found in the works of von Helmholtz, Donders and Tscherning.

OPTICAL CONSTANTS OF THE EYE

	Calculated Eye No. (A)	Calculated Eye No. (B)
Cornea		
Thickness	1 mm.	......
Index	1.333	......
Radius	8 mm.	......
Principal point at cornea.......	......	......
Nodal point behind it...........	8 mm.	......
Anterior focal length...........	24 mm.	......
Posterior focal length...........	32 mm.	......
Anterior focal power...........	42 D.	......
Posterior focal opwer...........	31 D.	......
Index of aqueous and vitreous.....	1.333	......

	Calculated Eye No. (A)	Calculated Eye No. (B)
Crystalline		
Thickness	3.6 mm.	......
Computed index	1.45	1.418
Relative index	1.089	1.0635
Anterior radius	10 mm.	......
Posterior radius	6 mm.	......
First equivalent point..........	2.1 mm.	2.15 mm.
Second equivalent point........	1.26 mm.	1.28 mm.
Focal length	43.86 mm.	60 mm.
Focal power	23 D.	16 D.
The Schematic Eye		
Length of optic axis............	22.2 mm.	24 mm.
Principal point	2.2 mm.	1.75 mm.
Nodal point	7.2 mm.	7.5 mm.
Principal point to nodal point...	5 mm.	5.75 mm.
Anterior focal length...........	15 mm.	16.5 mm.
Posterior focal length..........	20 mm.	22.25 mm.
Anterior focal power...........	66.66 D.	60 D.
Posterior focal power...........	50 D.	45 D.
Cornea to front of crystalline...	3.6 mm.	......
Cornea to back of crystalline....	7.2 mm.	......
Cornea to center of rotation.....	13.2 mm.	14 mm.
Nodal point to center of rotation.	6 mm.	6.5 mm.
Retina to center of rotation.....	9 mm.	10 mm.

IV. EXPERIMENTAL DETERMINATIONS OF THE OPTIC CONSTANTS OF THE EYE

25. Tscherning in his *Physiologic Optics*, gives the following brief table showing the constants of an eye measured as accurately as possible; some of the methods which he employed will be discussed elsewhere in this article.

Optic Constants of the Eye

Position of anterior surface of the cornea = 0.
posterior surface of the cornea = 1.15 mm.
anterior surface of the crystalline = 3.54 mms.
posterior surface of the crystalline = 7.60 mms.
Radius of anterior surface of the cornea = 7.98 mms.
posterior surface of the cornea = 6.22 mms.
anterior surface of the crystalline = 10.20 mms.
posterior surface of the crystalline = 6.17 mms.

The accepted values of the indices are:—index of air = 1, cornea = 1.377, aqueous = 1.3365, total index of the crystalline lens = 1.42, vitreous = 1.3365. Tscherning's data give for the *thickness of the crystalline lens* the value 7.60 — 3.54 mms. = 4.06 mms., while all the computations which we have made have been on the basis of von Helmholtz's determination of 3.60 mms. Tscherning's opinion is that the Helmholtz value is too small a number to be considered an average. According to Merkel it is 3.7 mms. The lack of agreement between these figures is doubtless due, in part at least, to the fact that, on account of the difficulty of observation, the number of individuals examined by any single investigator has not been large enough to establish a correct average. A thickness of 4 mms., as given by Listing, may be accepted as the normal standard.

26. A reference to the table of optical constants will disclose the fact that the *anterior surface of the cornea* is the most effective of the refracting media of the eye. The form of this surface has been most carefully studied by numerous investigators since the introduction of ophthalmometry by Helmholtz. A measurement of the cornea is laborious with Helmholtz's device, but the invention of the Javal-Schiötz instrument has made clinically possible that which was but previously essentially a laboratory experiment. Prior to the invention of the ophthalmometer it was customary to regard the normal cornea as the small end of an ellipsoid of revolution turning about the long axis. The early measurements showed that the cornea had a greater curvature at the center than at the periphery. But by use of the Javal-Schiötz ophthalmometer it was found that the cornea did not, as a whole, conform to any symmetrical surface. The conclusions reached by Sulzer are briefly as follows:—(1) The central region of the normal cornea differs but little from the segment of a sphere. (2) At a distance of about 2 mms. from the point of intersection of the visual line with the cornea the curvature begins to abruptly diminish. From this point on to the periphery the corneal surface shows a progressively decreasing curvature. (3) Whether we regard the point of intersection of the visual line with the corneal surface or the point of maximum curvature as representing the center of the cornea, the curvature does not diminish proportionately to the distance from this center. The average radius of curvature of the central portion of the anterior surface of the cornea is 7.829 mms., according to Helmholtz. Other averages do not differ much from this and a radius of 7.8 mms. is commonly accepted as the standard for the normal eye, representing a dioptric value of 43 D. approximately. From the researches of Schiötz on some 969 eyes we learn that the

radii may vary from 7.2 mms. to 8.6 mms. Examinations made by Tscherning on emmetropes showed that 35 per cent. of all such persons examined had a corneal radius of curvature of approximately 7.66 mms.

27. The *curvature of the posterior surface of the cornea* follows, in general, that of the anterior surface but approximates more closely to the spherical form. The average radius of curvature of the posterior surface of the cornea, which was first determined by Tscherning optically in a living eye by the use of the ophthalmophakometer, is given by him as 6.22 mms. These methods will be described and discussed under a separate caption farther along herein.

28. The refracting power of the cornea is about two and a half times greater than that of the crystalline lens. The sum of their refracting powers is not far from the total refracting power of the eye because the nodal points of the cornea, situated practically at its radius of curvature, some 8 mms. back of the anterior surface of the cornea, are very close to the nodal points of the lens. The following table shows the refracting powers of each of the surfaces:—

Anterior surface of the cornea	= + 47.24 D
Posterior surface of the cornea	= — 4.73 D
Anterior surface of the lens	= + 6.13 D
Posterior surface of the lens	= + 9.53 D
Total	= + 58.17 D

We see that the value of the posterior surface of the cornea is negative and almost equal in power to the anterior surface of the crystalline. But little error is made, however, by supposing that the substance of the cornea does not exist. By elimination of the negative effect of the posterior corneal surface the total refraction of the cornea would increase, but the power of the anterior surface diminishes nearly as much since we replace the index of the cornea by the weaker index of the aqueous. This simplification, neglecting the posterior corneal surface, gives the refracting power as 40.98 D instead of 42.16 D, which is an error of 1.2 D or about $\frac{1}{50}$ of the total power of the eye.

The following data are taken from Donders's *Accommodation and Refraction of the Eye,* as showing the influence of age and sex upon the radius of the anterior surface of the cornea:

(1) Radius in the line of vision—

	Maximum	Minimum	Average
In men	8.396	7.28	7.858 mms.
In women	8.487	7.115	7.799 mms.

(2) As to the influence of time of life—

In 79 men, average radius	= 7.858 mms.
In 20 men, under 20 years, average	= 7.932 mms.
In 51 men, under 40 years, average	= 7.882 mms.
In 28 men, above 40 years, average	= 7.819 mms.
In 28 men, above 60 years, average	= 7.809 mms.
In 38 women, average radius	= 7.799 mms.
In 6 women, under 20 years, average	= 7.720 mms.
In 22 women, under 40 years, average	= 7.799 mms.
In 16 women, above 40 years, average	= 7.799 mms.

29. The *curvatures of the crystalline lens* have been measured by the ophthalmophakometer. Much greater difficulty has been experienced in determining the exact forms of the surfaces of the crystalline lens than in the case of the cornea; but measurements made by Donders, Helmholtz, Knapp, Tscherning and others, show that when the ciliary muscle is relaxed the central portion of the anterior surface does not differ appreciably from the segment of a sphere having a radius of 10 millimeters and that the corresponding portion of the posterior surface equally resembles a segment of a sphere having a radius of curvature of 6 mms. Measurements made on 9 eyes by Stadfeldt and on 86 eyes by Awerbach show

	Stadfeldt	Awerbach
Anterior radius	10.95 mms.	10.43 mms.
Posterior radius	6.0 mms.	6.1 mms.
Depth of anterior chamber......	3.85 mms.	3.59 mms.
Thickness of the lens...........	3.65 mms.	3.90 mms.

The curves in Fig. 10 are taken as a resumé of the work of Awerbach. The number of eyes examined was not sufficiently large to be productive of regular or "smooth" curves but they do indicate admirably the variations in the different dimensions of the optical apparatus of the eye. The abscissæ indicate the dimensions in millimeters; the ordinates show the number of eyes examined which gave that dimension. In these diagrams R_1 represents the radius of the cornea, R_3 the radius of the anterior surface and R_4 the radius of the posterior surface of the lens, P the depth of the anterior chamber and E the thickness of the lens. It is probable, as Tscherning remarks with reference to these curves, that the differences of the dimensions of the optical portions of the eye correspond to analogous differences in other portions of the eyeball. One would expect to find larger radii of curva-

ture of cornea and crystalline in large eyes. For a radius of curvature of the anterior surface of the lens lying between 9 and 10 millimeters, there should correspondingly be an average corneal radius of 7.9 millimeters. In like manner one finds that large radii of curvature are correlated in turn with larger dimensions of the anterior chamber and of the crystalline. This is the significance of the double set of abscissæ attached to several of the diagrams given in Fig. 10.

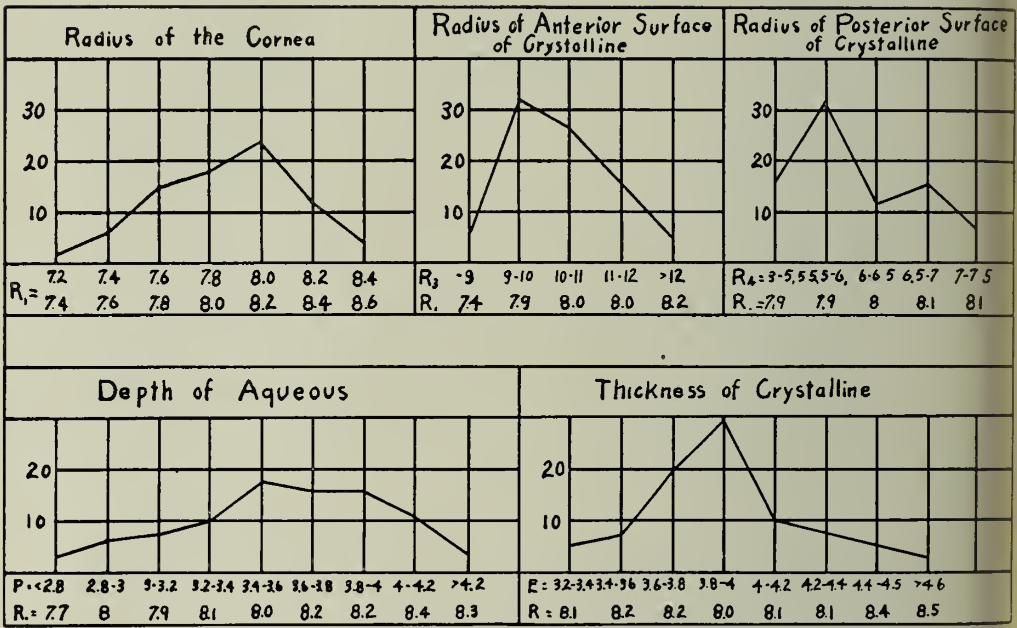


Fig. 10.—Curves Showing the Variations of the Dimensions of the Optical System of the Eye. (After Awerbach.)

Age and sex cause considerable variation in some of the radii of curvature of the various surfaces. The eye of the new-born child is much smaller than that of the adult, being about 17 millimeters axial length instead of 24 millimeters, and hence we might expect to find the curvatures of all surfaces increased in the same proportion. This is not so: Holth, by the clever device of injecting a solution of gelatine under the cornea as the aqueous was drained, measuring the anterior curvature and then carefully removing the cornea and thus, by contact of the gelatine with the inner side of the cornea, having a curve exactly mating it, obtained

	Man 44 yrs.	Woman 76 yrs.	Child 2 months
R_1	7.75 mms.	7.86 mms.	7.41 mms.
R_2	6.58 mms.	6.25 mms.	6.98 mms.

Axenfeldt's results are concordant with those of Holth. The dioptric power of the cornea varies from 40 to 47 dioptries and the values which are found in very young children are near to this upper limit. Compensation for the diminution in the length of an infant's eye is made by the crystalline. From the researches of Stadfeldt we learn that the thickness of the crystalline lens of a new-born child is the same as that of an adult, but the diameter is about 6 mms. instead of 8 or 9 mms., hence it follows that the curvatures of the crystalline surfaces are greater than for an adult. Stadfeldt's results are:—

	Anterior Radius = R_3	Posterior Radius = R_4	Thick-ness	Diameter
Adult	11 mms.	6 mms.	3.6 mms.	8-9 mms.
New-born ...	4.5 mms.	4 mms.	3.9 mms.	6 mms.

If the index of the child's crystalline is the same as that of the adult, its power would be nearly twice that of the adult or 32 D. power instead of approximately 16 D., and the crystalline refracting power would approach that of the cornea. We may reasonably doubt whether the index of the new-born crystalline is that of the adult eye since the hard nucleus does not exist in early childhood.

30. The *refractive index of the cornea*, which cannot be measured directly on the living eye, has a value of 1.377 as determined by Aubert, Matthiessen and Tscherning. The *indices* of the normal *aqueous* and *vitreous* are very exactly known and can be readily determined by various refractometer methods. Each has a value of 1.3365. This same value was also assumed by Helmholtz in his schematic eye as the index of the cornea. Fleischer gives 1.3373.

31. Less is known about the *index* of the *crystalline lens* than of any of the optical constants of the eye. The crystalline lens is not a homogeneous substance. Its refractive index gradually increases from the cortex to the nucleus. The curvature of the layers also diminishes as we pass from the center out to the peripheral layers. Each layer takes the form of a meniscus, the concavity of which is greater than the convexity. This conclusion follows both from anatomical and optical observations.

After death there is frequently produced a differentiation between the cortical and nuclear masses probably caused by the soaking up of water by the superficial parts. In consequence of this there are

five, instead of three, images of Purkinjé. The three reflections of, for example, a candle come from the convex cornea, the convex anterior surface of the crystalline and the concave posterior surface of the crystalline, all being regarded as reflecting or mirror surfaces. The two extra images come from the convex anterior surface of the nucleus and the concave posterior surface of the nucleus. Fig. 11 (A) gives the Purkinjé images of an ox eye (dead). The positions of these images indicate that the curvature of the surfaces of the nucleus is considerably greater than that of the true crystalline surfaces. In Fig. 11 (A), (a) is the image of the cornea, (b) image of anterior

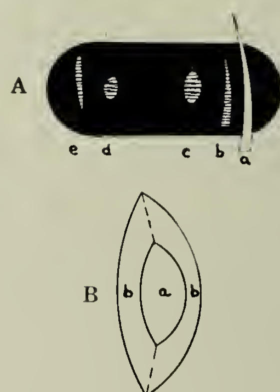


Fig. 11.—(A) Images of Purkinjé of the Eye of an Ox (dead)—Flames of a Candle. (After Tscherning.)

a. Image of cornea; *b.* image of the anterior surface of the crystalline lens; *c.* image of the anterior surface of the nucleus; *d.* image of the posterior surface of the nucleus; *e.* image of the posterior surface of the crystalline lens.

— (B) Illustrating the Curvature of the Nucleus and Cortical Parts of the Eye.

surface of the crystalline, (c) image of anterior surface of the nucleus, (d) image of posterior surface of the nucleus, (e) image of posterior surface of the crystalline lens. Fig. 11 (B) roughly diagrams the relative curvatures of nuclear and superficial layers. Demicheri has described alterations of the crystalline lens giving four images (since the images from the posterior nucleus and posterior crystalline surface coincide) which he has called *faux lenticoné* and giving the same phenomena which one observes in keratoconus.

The crystalline lens is, therefore, not homogeneous but is made up of a great number of superimposed layers whose curvatures increase in passing from the surface toward the center so that the nucleus is nearly spherical. The index of refraction also increases from without inward, so that the crystalline lens may be considered as composed

of so many divergent menisci increasing in power proportionately to their proximity to the nucleus, which in turn is a convex lens of a very short radius and high index of refraction. The effect of such a structure of the lens is to diminish spherical aberration, i. e., to permit of the formation of distinct images even by rays which enter the eye at a considerable angle with the optic axis. A homogeneous lens brings to a single focus only such rays as pass through near its center. The lamellar structure of the crystalline lens peculiarly adapts it for indirect vision in which retinal images are produced by the rays which form a considerable angle with the axis of the eye.

32. The peculiar structure of the crystalline lens has still another effect, for it renders the dioptric power of this lens greater than if it were homogeneous. Indeed, its *total index,* which is to say the index of an imaginary lens having the same form and same focal length as the crystalline lens, is greater than not only the mean value of the crystalline layers but even that of the nucleus. This seems paradoxical, but it is easy to convince one's self of its truth. Suppose the crystalline lens divided into two parts, the cortical and nuclear, as depicted in Fig. 11 (B), and suppose the index uniform in each part but greater in the nucleus. The cortical menisci, being divergent in form and power, neutralize a part of the positive refractive power of the nucleus. This neutralization is greater in proportion as the index of refraction of the cortical layers increases, because the refractive powers of the menisci increase in like proportion. Hence the refractive power of the crystalline lens would be less if the index of refraction of the cortical laminæ was equal to that of the nucleus.

The question of the crystalline refraction and its total index of refraction is one of the most complicated problems in ocular dioptrics. Since the indices increase in value from without toward the center, the problem becomes analogous to that of the refraction of the atmosphere in which the indices change from layer to layer.

33. Thomas Young was the first to establish the total index of the crystalline. He measured the index of the center of the nucleus and placed it at 1.0588 with respect to the aqueous or 1.412 with reference to air. In order to calculate the index he assumed a crystalline of spherical shape of radius R with a nuclear part having a radius r_a and index equal to n_o, which index decreased in value toward the periphery in the inverse ratio to some power, k, of its distance from the center. The index, n_1, at any point is

$$n_1 = n_o\left(\frac{r_a}{r}\right)^k$$

The total index, N, was calculated from the formula

$$N = n_o \frac{1 - K}{\dfrac{n_o}{n_1} - K\left(\dfrac{n_o}{n_1}\right)^{\frac{1}{K}}}$$

Since the values of the central and peripheral indices, n_1 and n_o respectively, are known and their radii R and r_a then K can be found as

$$\left(\frac{n_o}{n_1}\right)^{\frac{1}{K}} = \frac{R_a}{R} = 4$$

The ratio $\dfrac{n_o}{n_1} = 1.0164$ and therefore

$$\sqrt[K]{1.0164} = 4 \text{ and } K = \frac{\log.\ 1.0164}{\log.\ 4}$$

This value, when substituted in the equation for N, gives the value of $N = 1.075$ relative to the aqueous or 1.436 as the total index with reference to air. This optical procedure is an interesting application of the mathematical methods involved in the Newtonian theory of attraction. Matthiessen, in his work, deduced a theorem known as the law of Matthiessen, which states that the total index may be found by taking the difference between twice the central index and the cortical or, in terms of the notation as used in this paragraph,

$$N = 2\,n_o - n_1$$

This gives a total index of 1.437. Stadfeldt and Tscherning determined the total index of the crystalline by entirely different methods and arrived at a value of 1.42. This value is considered rather low by most authorities. Stadfeldt's results on 11 eyes, enucleated within thirty-six hours after death, show the following data on the crystalline lens.

Sex	Age	Thickness (Lens)	Anterior Radius $= R_1$	Posterior Radius $= R_2$	Focal Length (mms.)	Total Index $= N$
M	45	3.67	10.89	6.49	51.933	1.4390
M	45	3.78	11.25	6.43	50.353	1.4430
M	50	4.06	10.55	6.404	54.482	1.4322
M	50	3.99	10.714	6.193	52.618	1.4341
M	40	3.85	9.782	6.428	50.138	1.4371
M	40	3.78	11.175	6.424	54.61	1.4339
F	31	4.24	10.887	5.720	48.832	1.4370
F	25	3.99	8.437	5.819	41.994	1.4434
F	25	3.64	8 654	5.72	43.014	1.4410
M	32	3.64	12.981	6.25	59.44	1.4297
M	32	3.50	12.981	6.08	55.839	1.4339
	Average	3.83	10.75	6.18	51.21	1.4368

W. Krause found as the index of the external layer 1.4053, for the intermediate 1.4294 and for the nucleus 1.4541. Woinow gives 1.3932, 1.4199 and 1.4315 respectively.

V. OCULAR CATOPTRICS AND THE MATHEMATICAL PRINCIPLES OF OPHTHALMOMETRY AND OPHTHALMOPHAKOMETRY AND THEIR APPLICATIONS

34. Ophthalmometry, or keratometry, is the measurement of corneal curvature and particularly, in practice, of the determination of the differences in the curves in order to determine the amount of corneal astigmatism.

The cornea, having a clear reflecting surface, acts as a convex mirror and the laws governing the conjugacy of foci of mirrors may be applied here.

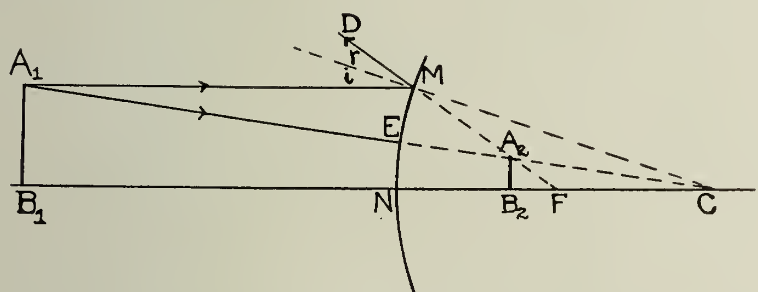


Fig. 12.—Illustrative of the Laws of Reflection and Formation of Images in Convex Mirrors.

35. Let MN be the reflecting surface of a convex mirror. Let A_1B_1 be the object. In order to find the image position we proceed as in Fig. 12. CN represents the radius of curvature; the point N is the pole.

We proceed as follows:—(1) A ray of light, A_1M, parallel to the principal axis, B_1C, will strike the convex mirror at the point M. According to the laws of reflection at plane surfaces, considering an infinitesimal unit plane at M, the angles of incidence *(i)* and reflection *(r)* are equal and the ray after reflection travels in the direction DM. This ray when projected backwards will cut the principal axis at a point F, half way between the pole N and the center C, known as the principal focus.

(2) A ray A_1E, directed toward the center of curvature, will proceed normally to the spherical surface and will, therefore, after reflection travel back upon itself. The return ray, EA_1, when projected backward, will necessarily cross the principal axis at C.

(3) The projections of the two rays DM and EA_1, which are the paths of the incident rays A_1M and A_1E proceeding from A_1, intersect at A_2 behind the mirror. This locates the image of the object point A_1 at A_2; the image is virtual, erect and smaller than the object. The rays, MD and EA_1, actually reflected, are divergent in the initial medium.

$$\text{Let } FC = F = \frac{R}{2} = \text{principal focal length}$$

$$NB_2 = f_2 = \text{image distance}$$
$$NB_1 = f_1 = \text{object distance}$$
$$B_2C = NC - NB_2 = R - f_2$$

The triangles A_1CB_1 and A_2CB_2 are similar, hence

$$\frac{O}{I} = \frac{A_1B_1}{A_2B_2} = \frac{B_1C}{B_2C} = \frac{f_1 + R}{R - f_2} \quad \text{.....................(1)}$$

From triangles MNF (considering MN as a straight line, which is permissible when the aperture of MN is small) and A_2B_2F,

$$\frac{O}{I} = \frac{MN}{A_2B_2} = \frac{A_1B_1}{A_2B_2} = \frac{NF}{B_2F} = \frac{F}{F - f_2} \quad \text{...........(2)}$$

Hence $\dfrac{f_1 + R}{R - f_2} = \dfrac{F}{F - f_2}$ or, by clearing,

$$f_1F - f_1f_2 - Rf_2 = - f_2F.$$

But $Rf_2 = 2\,Ff_2$, hence

$$f_1F - f_1f_2 = Ff_2 \quad \text{.................................(3)}$$

Dividing all terms of equation (3) by f_1f_2F, we obtain

$$\frac{1}{f_2} - \frac{1}{F} = \frac{1}{f_1} \text{ or}$$

$$\frac{1}{f_1} - \frac{1}{f_2} = -\frac{1}{F} = -\frac{2}{R} \quad \text{...........................(4)}$$

This is the fundamental law connecting the conjugate foci f_1 and f_2 in the case of reflection. The general form of this equation is

$\frac{1}{f_1} + \frac{1}{f_2} = \frac{2}{R}$; in the case of a convex mirror f_2 and R are negative quantities, as to direction only, since they are measured from the pole in a direction opposite to that in which the object distance f_1 is measured.

Likewise it can be demonstrated that

$$\frac{A_1B_1}{A_2B_2} = \frac{O}{I} = \frac{f_1}{f_2} \quad \ldots\ldots (5)$$

If *MN* be considered the cornea, which has a large curvature, and B_1N, the object distance, be great in comparison with B_2N, the image distance, we may then assume without appreciable error that the image A_2B_2 will be formed at the principal focus, F. Hence we may write

$$f_2 = F = \frac{R}{2} \quad \ldots\ldots (6)$$

Therefore, the equation (4), $\frac{1}{f_1} - \frac{1}{f_2} = \frac{-2}{R}$, becomes, upon substitution of the value of f_2 from equation (6), $\frac{1}{f_1} - \frac{2}{R} = \frac{-2}{R}$ or f_1 is infinity. This point is inserted at this place to call the attention of the reader to the fact that infinity, optically considered, is after all nothing but a relative quantity, that is to say—a ratio.

A substitution of f_2 (equation 6) in equation (5) gives

$$\frac{R}{2f_1} = \frac{I}{O} \quad \ldots\ldots (7)$$

whence $R = \frac{2f_1I}{O}$ ......(8)

The exact formula, which can be derived from the preceding expressions, is

$$R = \frac{2f_1I - R}{O}$$

36. Equation (8) is the *fundamental equation of ophthalmometry;* one must of necessity then measure the distance of the object and its size before the curvature of the cornea can be determined. The size of the image is the difficult measurement to obtain. Two luminous objects, called *mires,* are used in an ophthalmometer and the distance between them is a measurable quantity. The image, then, is the distance separating the images of the mires. Physicists use a micrometer placed at the focus of the objective of a telescope with which the image is observed. The objective forms an image on the micrometer, the graduations of which permit the size of the image to be read directly by observing it through the eyepiece. This method cannot be employed with the human eye because the observed eye cannot be kept absolutely stationary. To obviate this defect, Helmholtz intro-

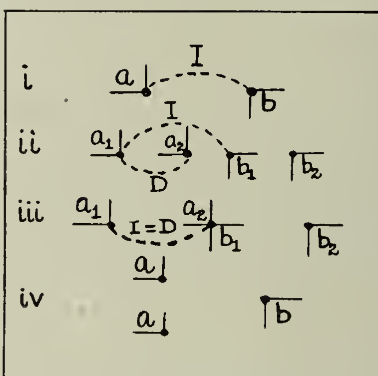


Fig. 13.—Illustrating the Principle, of Doubling (dédoublement) as Applicable to Ophthalmometry.

duced the principle of doubling (dédoublement); Thomas Young (1801) had, however, already made use of this same method, borrowed from astromony, for the same purpose. Suppose, therefore, that we wish to measure a distance I separating the two points a and b and that we have some process (such, for example, as plane parallel plates of glass placed obliquely behind the objective but in a symmetrical manner in relation to the axis of the telescope), which permits us to see everything doubled at a certain distance D. In Fig. 13 (i) let a and b be two such points originally. By the doubling process we shall see four points, Fig. 13 (ii) a_1 and a_2, b_1 and b_2, and the distance a_1a_2 would be equal to b_1b_2 and to D, while the distance $a_1b_1 = a_2b_2 = I$. Suppose we now vary the doubling; for example, by changing the inclination of the plates obliquely placed behind the objective of a telescope. By increasing the doubling it will be possible to cause a_2

and b_1 to coincide, Fig. 13 (iii), and at that instant $I = D$. If we know the amount of doubling we shall then have measured $I = ab$. Instead of causing the doubling to vary it is possible to make I vary; this is accomplished by varying the distance between mires, the doubling device remaining constant in its value.

37. It is generally desirable to employ a certain magnification in order to make measurements easily and with accuracy. This is accomplished by a telescope. Essentially, then, an ophthalmometer consists of a telescope, the luminous mires and the doubling apparatus. The cornea under observation is approximately at the one symmetrical plane of the objective of the telescope and its real image at the conju-

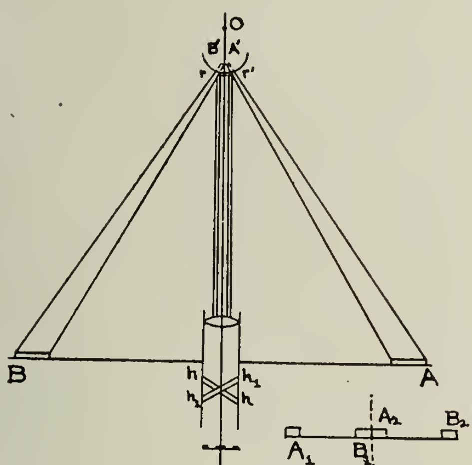


Fig. 14.—Optical Principles of the Ophthalmometer.

gate point for the objective; this first image is at the focal plane of the eye-piece which furnishes the observer with a magnified inverted image of the corneal reflections. The doubling apparatus is placed either between the components of the objective, as in the Javal instrument, or in the convergent light from the latter. In the modern form of instrument of Javal and Schiötz two luminous mires are made to slide along a metallic arc by means of a revolving drum device and it is the distance between them which serves as the object. By moving the mires on the arc the size of the object is made to vary until it corresponds to the constant doubling value of the prism device. The doubling device is a Wollaston prism composed of two rectangular quartz prisms which are cemented together so as to form a single, thick, plane parallel plate; the two prisms are cut from quartz so

that the apex of one is parallel to the optic axis of the crystal and the other perpendicular to it. The Wollaston prism is so placed as to double in a direction exactly parallel to the plane of the arc. When the second and third images of the four produced by the doubling prism are in contact, the radius and the power of the cornea can be read off on the scale attached to the disc of the instrument. A diagrammatic scheme of the essential principles of ophthalmometry is shown in Fig. 14. Fig. 15 gives the Javal-Schiötz doubling device.

38. We have stated that the disc or the arc is graduated in diopters

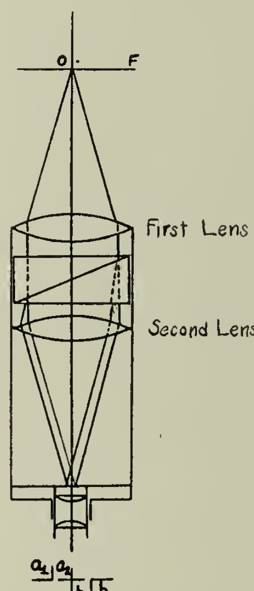


Fig. 15.—Optical Apparatus of Javal's Ophthalmometer (with contact of doubled images in lower diagram.)

in such a manner that one degree corresponds to one diopter. This can be explained and the method of computing the amount of doubling produced by the prism calculated. Javal and Schiötz took as the index of the cornea and aqueous the value 1.3375. The focal length of the cornea is

$$F_C = \frac{R}{n - 1} = \frac{R}{1.3375 - 1}$$

The refracting power, D_C, is $D_C = \frac{1}{F_C} = \frac{n-1}{R}$ or, expressing

R_C in millimeters,

$$D_C = \frac{337.5}{R_C} \text{ or } R_C = \frac{337.5}{D_C}$$

By means of this formula one can calculate the relations between refracting powers of the cornea and the corresponding radii expressed in millimeters. Some of the values thus obtained are:—

Refraction (Diopters)	Radius (Millimeters)
50	6.75
48	7.03
46	7.34
45	7.50
43	7.85
41	8.23
39	8.65
38	8.89

The general ophthalmometric formula is

$$\frac{O}{I} = \frac{2f_1}{R_C} \quad \ldots\ldots (1)$$

and since $$R_C = \frac{337.5}{D_C} \quad \ldots\ldots (2),$$

therefore, $$O = \frac{2f_1 D_C I}{337.5} \quad \ldots\ldots (3),$$

in which I designates the image which, at the moment of contact, is equal to the doubling. This is the condition diagrammed in Fig. 13 (iii). Let a denote the linear length of a degree on the scale of the arc: this can be readily calculated from the relation that the radius multiplied by the angle at the center, expressed in radians, is equal to the arc. If this length must correspond to one diopter, the object which corresponds to the image I must have the linear size $D_C \cdot a$. Hence

$$D_C \cdot a = \frac{2f_1 \cdot D_C \cdot I}{337.5}$$

$$\text{or} \quad a = \frac{2f_1 \cdot I}{337.5} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

But $a = 1°$ in length, hence

$$\frac{1°}{360°} = \frac{a}{2\pi f_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where $2\pi f_1$ represents the circumference of the circle of which the ophthalmometric arc is a portion and a represents an arc corresponding to the linear length of a degree. Therefore, from equations (4) and (5)

$$a = \frac{2\pi f_1}{360} = \frac{2f_1 \cdot I}{337.5}$$

$$\text{or } I = \pi \frac{337.5}{360} = 2.94 \text{ mms.}$$

In order, therefore, that a degree of the arc may correspond with one dioptry the doubling of the prism must be 2.94 mms. The radius of the arc can be so selected as to give the linear length of a degree any value desired. Suppose one desires this length to be 5 millimeters. Then, since the value of the radius of the arc, f_1, in millimeters, multiplied by the angle in radians is equal to the arc in millimeters and one radian is approximately 57.3°, we have

$$f_1 \times \frac{1}{57.3} = 5 \text{ millimeters}$$

$$\text{or } f_1 = 286.5 \text{ millimeters.}$$

Now suppose a living cornea to be examined. Having focused the telescope, four images are seen, the two central ones being closer together: we regard these two images only, wholly neglecting the outer two. The central images can be made to touch by means of the rack controlling the mires. If the cornea is spherical these images will remain in contact as the telescope and arc are rotated through any meridian. If there is corneal astigmatism, the distance between the two images will vary, as the arc is rotated, on account of the variation in curvature; likewise the images will have an eccentric sliding motion with respect to each other and the central lines of the

mires will be broken. Rectangular objects, for instance, will give rectangular images when the plane of deviation of the prism corresponds with either one of the principal meridians. In any oblique meridian, the rectangles will be distorted so as to appear as oblique parallelograms. This phenomenon is due to toric reflection from surfaces having compound curvatures; one of the images will be higher than the other, which accounts for the discontinuity of the middle lines of the mires.

39. *Artificial astigmatism.* A standard reflecting surface comes with many ophthalmometers, used with cylindrical lenses from trial cases to produce artificial astigmatism. A truly astigmatic artificial cornea does not permit of the obtainance of any variation in the amount of astigmatism however. If a convex cylinder is placed with its curved surface in contact with the sphere there is a reduction of the negative reflecting power across the axis, while a concave cylinder similarly placed increases it; in both cases the power parallel to the axis is unchanged. Let R be the reflecting power of the sphere, D the refracting power (on an index of 1.3375) and P the power of the cylinder. Suppose the cylinder to be convex. Then the combined reflecting power of the sphere and cylinder is $R - 2P$ since the focal length of a plano-convex cylinder is zero in one meridian and has a value in a meridian at right angles thereto equal to $2r$, where r is the radius of the curved surface, when the index equals 1.5, hence a reflecting power of $2P$. The refracting power across the axis as compared with the meridian parallel to the axis is $\frac{D(R-2P)}{R}$, so that the artificial astigmatism produced is:

$$\text{Astigmatism} = \frac{D(R-2P)}{R} - D = -\frac{2P \cdot D}{R}$$

The normal cornea can be assumed as having a radius of 7.5 mms. The focal length of a mirror of radius 7.5 mms. is one-half the radius or 3.75 mms. Hence the reflecting power of a standard sphere representing the cornea is 266 D. Its refracting power is 45 D. Therefore the ratio of the reflecting to the refracting power is nearly 6 to 1. Hence D = 45 diopters and R = 266 diopters and as a consequence

$$\text{Astigmatism} = \frac{2 \times 45 \times P}{266} = \frac{P}{3}$$

We thus find that the artificial astigmatism produced is approximately one-third the power of the cylinder producing it. Thus, if the cylinder used be + 3 D., the astigmatism produced is + 1 diopter; if P = — 6 D., then the astigmatism created is — 2 diopters; the signs refer only to the character of the astigmatism produced; the addition of plus cylinders produces an artificial hyperopic astigmatism while minus (concave) cylinders produce an artificial myopic astigmia. Furthermore, it will be found that the artificial astigmatism produced by the addition of a cylindrical lens to the standard cornea (of glass) is approximately *one-half* of the power of the cylinder producing it if we make use of the artificial corneas furnished by American manufacfacturers of ophthalmometers. In a preceding paragraph we gave the ratio as one-third instead of one-half. The following abbreviated calculation shows that, while the power of the artificial cornea may be the same, i. e., 45 diopters, the index of glass is approximately 1.5, whereas that of the true cornea is 1.3375. Hence, since D = 45 diopters, n = 1.5 and D = (n — 1) 1000/r (mms.), then r = 500/45 = 11 mms. (approximately). Therefore the reflecting power of this standard cornea is equal to 1000/5.5, or, 180, practically. Hence

$$\text{Astigmatism} = \frac{2 \times 45 \times P}{180} = \frac{P}{2}$$

Three points in practice need mention:—(1) the distance from the mires to the standard reflecting sphere may be neglected as not affecting the calculations, (2) the curved surface of the cylinder must be in contact with the cornea and (3) the ophthalmometer must not be refocused between the first and second positions even though the thickness of the glass along the axis causes a slight blurriness in the image.

40. *Results of the measurements on the human cornea.* Only a very small part of the cornea is used for measurement; likewise the portion upon which measurements are made is at or near the visual line, since the patient is ordinarily directed to look into the telescopic opening unless the peripheral parts of the cornea are desired. In Fig. 16, *AB* represents the distance apart of the mires considered as points; *CN* represents the distance of the mires from the cornea. *F* represents the focal length of the cornea considered as a convex mirror; we shall assume at this point so small an image of *AB* at *F* as to practically amount to a single image point only. The triangles ABF and DEF are similar; hence

$$\frac{AB}{DE} = \frac{CF}{NF}$$

CN in the ordinary ophthalmometer is about 300 millimeters; *NF* for the assumed normal cornea is 3.75 mms.; our previous calculations of 5 mms. as representing the linear value of 1 diopter refracting power and the cornea having a power equal to 45 D., gives *AB* the value of 225 mms. Then $\frac{225}{DE} = \frac{300}{3.75}$ or DE = 2.8 mms. This shows that the images of the mires are formed by reflection from two small parts of the cornea situated about 1.4 mms. from the visual line CNF (Fig. 16).

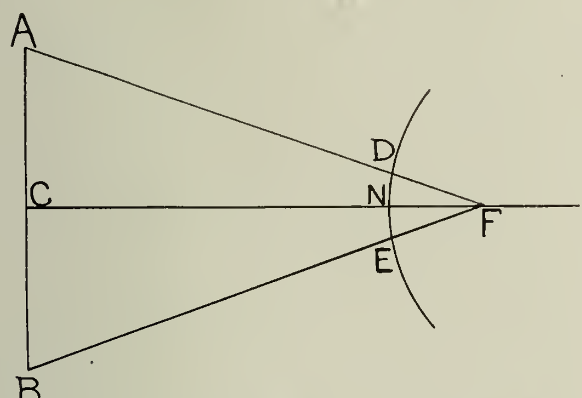


Fig. 16.—Simple Diagram Representing Relative Positions of Mires (A and B), and Cornea (D E) in Ordinary Ophthalmometer.

41. The radius of the cornea at the summit varies between 7 and 8.5 mms. Cases of keratoconus exceed this limit. Tscherning and Bourgeois examined a considerable number of emmetropes and found an average radius of curvature of 7.8 mms. Fig. 17 gives the curve obtained from the researches of these men; the abscissæ indicate the radii of curvature of the cornea in millimeters and the ordinates the number per hundred of emmetropes in whom there was found the radius of curvature specified. The value of R = 7.8 mms. is probably high, for Tscherning states that the persons examined were tall in stature and of large craniai circumference. Likewise Steiger has since found a more manifest relation between the radii of curvature of corneæ and the distance between the eyes.

Discussing corneal curvatures, Edward Jackson *(Ophthalmology,* Vol. XIII) gives the following tabulation:

Corneal Curvatures Among 2,000 Eyes

Radius of Curvature	Number of Eyes	Percentage
Under 6.5 mm..................	6	0.3
6.5 to 7 mm....................	10	0.5
7 to 7.5 mm....................	305	15.25
7.5 to 8 mm....................	1,263	63.15
8 to 8.5 mm....................	409	20.45
8.5 to 9 mm....................	2	0.1
Over 9 mms....................	5	0.25

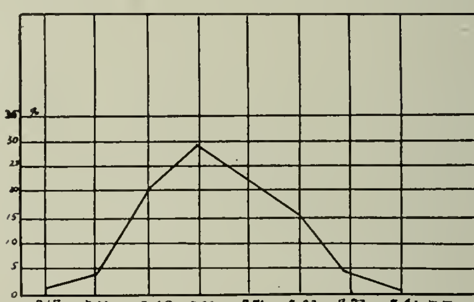


Fig. 17.—Curve Showing Relation between Radii of Curvàture of Cornea (in millimeters) and Percentage of Emmetropes in whom the Radius of Curvature in Question Occurs. (After Tscherning.)

It would be an error to presume that one radius rather than another corresponds to emmetropic conditions. It may be safe to say with Tscherning "that in emmetropic eyes there exists a constant relation between the radius of curvature of the cornea and the length of the ocular axis, so that the ocular shell of different emmetropic eyes would always be a reproduction of the same type, a little enlarged or a little diminished." It is still an open question as to whether there exists such a thing as myopic and hyperopic corneal curvatures, although Sulzer presented some evidence in support thereof at the 1896 Congress of the French Society of Ophthalmologists; it doubtless does exist in cases of very high hyperopia which approach microphthalmia. Even in cases of anisometropia, excepting, however, cases of astigmatism, there is generally under a half diopter's difference between the corneal refraction of the two eyes.

42. *The form of the anterior surface of the cornea.* Previous to the invention of the Javal-Schiötz instrument, ophthalmometry was a difficult procedure. By their invention they made the ophthalmometer a clinical instrument. Up to their time but little was known as to the form of the cornea. The ophthalmometer of Helmholtz was a complicated device; one was forced to measure three points on a meridian, one corresponding to a point on the visual axis and the other two situated at some distance from it, there being one on each side of this line. The peripheral rays were found to have a greater radius than those which came from the central portion; hence it was obvious that the cornea could not be assumed to be a portion of a spherical surface.

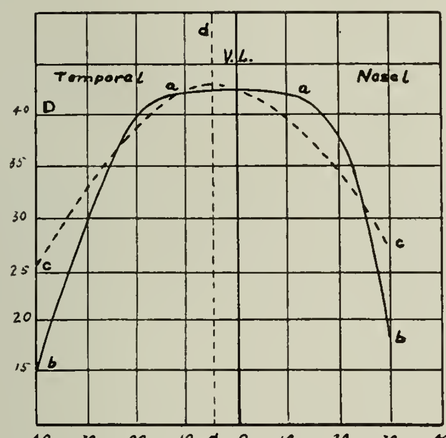


Fig. 18.—Diagram of Corneal Refraction. (After Ericksen.) The abscissas indicate the distance of the visual line in degrees and the ordinates the corneal refraction in diopters.

As a consequence the curvature of the second degree which approached most closely the observed data was constructed and calculated. Hence there arose the belief that the form of a non-astigmatic cornea was an ellipsoid of revolution around the long axis, which axis departed from the visual line outwardly, forming an angle, known as the angle *alpha* (α), of about 5 degrees with this line. (The angles *alpha*, *gamma* and *kappa*, so-called, will be discussed elsewhere in this article.) The dotted curve *cc* in Fig. 18, corresponds to an ellipsoid calculated from the three measurements taken at 0° and 25° on the right and left sides of the visual axis: the line *dd* is the axis of this ellipsoid and passes to the temporal side of the visual line, *V.L.*, or the zero degree line by an angular amount of about 5°, representing the angle alpha. The full line curve, *bb*, shows the refraction of the horizontal meridian

of a cornea measured in graduations of five degrees. We see that the true form of the cornea differs considerably from the ellipsoid. The method as employed by Javal and Schiötz, which, parenthetically it may be said, can be readily repeated by anyone so desiring, was to divide the keratoscopic disc into 5 degree graduations by narrow concentric rings. After having made the measurements along the visual line when the patient looks at the center of the objective, the measurements are repeated with the observed party fixing upon the 5°, 10° and so forth points, both to the right and left of the central fixation point, the head remaining immovable. Every meridian may be tested in the same manner. Some measurements made in this manner by Sulzer and Eriksen are diagrammed in Fig. 18; these results confirm the statements of Aubert and Matthiessen who made use of the Helmholtz ophthalmometer and affirmed that the cornea could be divided optically into two parts:—(a) a central one (*aa* Fig. 18) approximately spherical and normally chiefly operative in vision and (b) a peripheral portion (*ab* or *ac* Fig. 18) which is much flattened. Eriksen, from the averages of measurements made on 24 eyes, gives the following as the limits of the optic part of the cornea in comparison with its entire value in degrees.

	Optic Portion	Total Cornea
Outwards	16.5°	44.7°
Inwards	14°	40.1°
Above	12.5°	38.5°
Below	13.5°	42.2°

The total of the optic part of the cornea is about 30° horizontally and 25° vertically; the total width of the cornea is about 85° horizontally and 80° vertically.

No axis of symmetry, properly speaking, has been found by any observer. Most of the results, however, show a tendency to symmetry about an axis directed about 5° outward and a little below the visual line.

43. Eriksen tried to obtain information as to the variation of the peripheral radii by examining the form which the image of a white square assumes in the horizontal meridian at different distances from the visual line. These results are shown in Fig. 19, in which the upper numerals indicate angular distances from the visual line; the lower figures show the dioptral refraction. At about 30° from the visual line, the horizontal meridian being under test, the image is horizontally some two and a half times greater than at the center.

At the extreme periphery the image becomes narrower and at 33° is an upright rectangle; at this point double images may be obtained, one of which may be inverted in the horizontal direction indicating that the curvature increases very considerably toward the border and that there may be, and doubtless is in many eyes, a concavity at the sclero-corneal border.

The obliquity of the cornea plays but a small part as far as the optics of the eye is concerned since the optic part of the cornea is nearly spherical; this sphericity holds over a linear cross-sectional diameter of about 4 mms. When the pupil is very large the *basilar* or peripheral parts may produce certain changes in the refractivity of the eye in the peripheral regions thus producing marked spherical aberration effects. But the position of the pupil varies considerably in different eyes; Sulzer found that on an average the center of the pupil is temporalward from the visual line about 5° but may be dis-

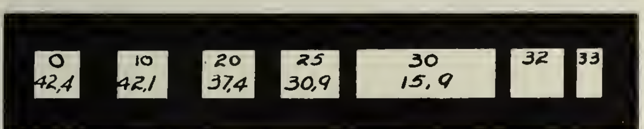


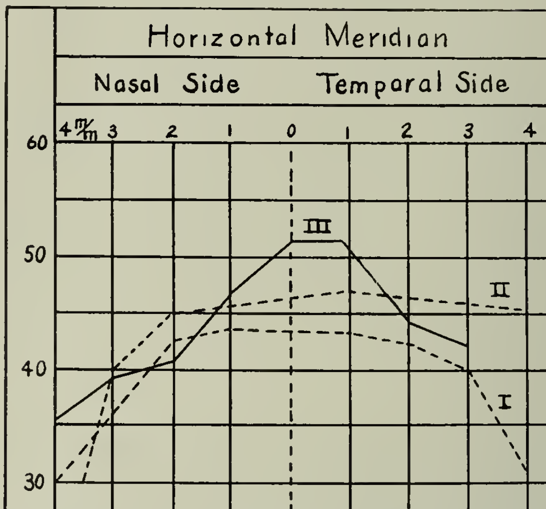
Fig. 19.—Forms of the Image of a White Square at Different Parts of the Cornea. Horizontal meridian, internal half. (After Ericksen.)

The figures at the top of the squares indicate the distance in degrees from the visual line. Those at the bottom the refraction (in the horizontal meridian) in dioptries.

placed either upwards or downwards. This decentering of the pupil may compensate for the obliquity of the cornea, therefore ,the most marked effect of the peripheral flattening would be temporalward.

44. While the curvature of the normal cornea varies between 40 and 48 diopters, higher values are found in cases of keratoconus. It is not uncommon to find cases of 60 to 80 diopters; indeed Cordiale found a case in which the curvature attained a value of 100 diopters which corresponds to a radius of curvature of 3.4 millimeters. Another case, more pronounced but irregular, had an apex radius of curvature of 2.2 mms. The summit of the curve showing corneal curvatures is usually situated about 1 millimeter from the visual line. Fig. 20 (A) gives the results on the radii of corneal surfaces in the horizontal meridian; Curve I is for a cornea of low curvature, Curve II of high curvature and Curve III keratoconus. Fig. 20 (B) gives similar results for the vertical meridian, the numbers of the curves having the same significance as in Fig. 20 (A). In both figures the abscissæ

indicate distances from the visual line in millimeters while the ordinates represent the refractive power in diopters.



Corneal Radii of Curvature. (After Cordiale.) Curve I. Cornea of low curvature; Curve II, of high curvature, and Curve III, for Keratoconus.

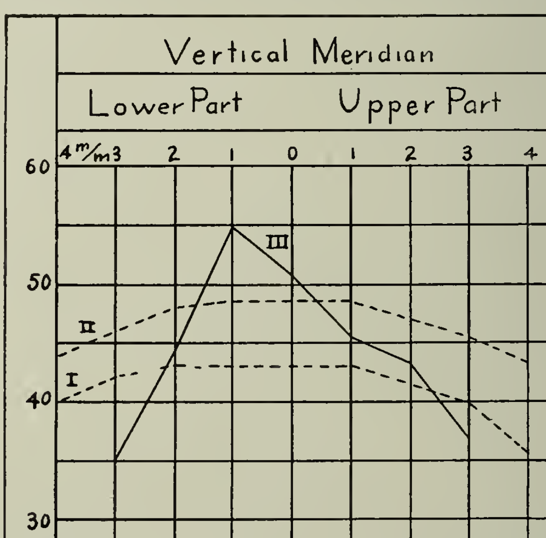


Fig. 20.—The abscissas indicate the distances from the visual lines in millimeters; the ordinates the refraction in diopters.

45. The methods of Sulzer and Eriksen afford very excellent notions as to the form of the cornea but they do not give any direct

conclusions as to the refraction at its periphery and are not directly applicable to ocular dioptrics. The reason is obvious when we consider the fact that, while the cornea is not a true ellipsoidal surface, it crudely approaches it and is, roughly speaking, a surface of revolution of the second degree. In Fig. 21 let ES be a parabolic surface, R a luminous point, F_2 its image, EC the normal and EH the radius of curvature. The refraction of the light from the luminous point R at the surface point E takes place in the same manner as if the surface were replaced at this point by a sphere drawn around the point C where the normal EC meets the axis. If N designates the value of EC, the normal, then, as previously proven, the dioptric power is $D_C = \frac{n - 1}{N}$. It is experimentally necessary, therefore, to calculate the

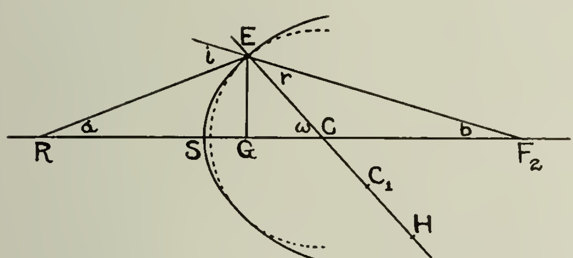


Fig. 21.—Refraction by a Parabolic Surface.

aberration produced by a peripheral flattening of the cornea and in order to do so the values of the normals must be known. To this end Brudzewski replaced the arc of the Javal ophthalmometer by one reaching to 170 degrees. One of the mires was fixed at the middle of the arc so that its border when prolonged would pass through the axis of the telescope, while the other mire was moved on the arc until it made "contact" of images. The observed party fixed the middle of the objective throughout the tests. Brudzewski used prisms of different doubling powers. Having obtained contact he used, for example, a prism doubling 1 millimeter. The arc being placed horizontally he determined the position on the nasal side which the movable mire must have so that contact might be obtained. This process was repeated on the temporal side, putting the arc vertical. These measurements gave the lengths of the *normals* at four points situated one millimeter from the visual line. These measurements were then repeated with prisms of 2, 3 and 4 millimeters doubling power. Knowing the normals, the aberration produced by the corresponding part of the cornea can be

found. Fig. 22 will aid in elucidating this method. By the method of Brudzewski one measures the normal at a given point of the cornea; that is to say, the portion of the normal comprised between the surface and the visual line. Let *BL*, Fig. 22, represent the cornea; let *BO* and *EO* be two normals to the cornea and *KC* the visual line. In order to measure the cornea at *E* according to the method of Eriksen the ophthalmometer is directed along the prolongation of *CE* and hence measures the length of *OE* or the radius of curvature at *E*. According to the method of Brudzewski, on the contrary, one directs the ophthalmometer along the visual line *KC*. Considering, then, the instrument placed at a great distance, relatively speaking, from the

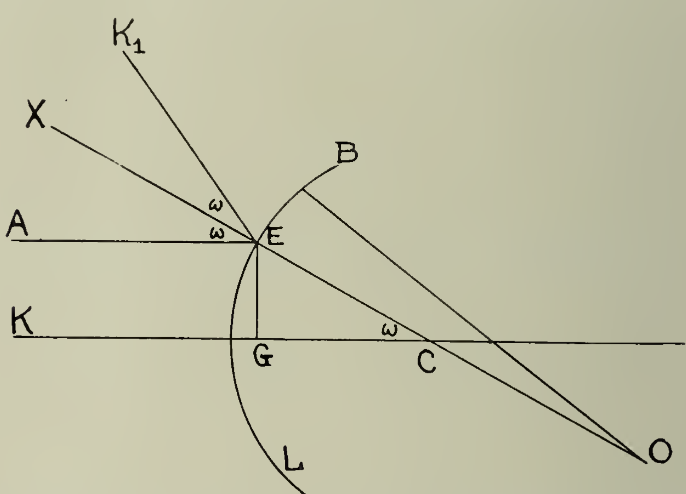


Fig. 22.—Sketch Illustrating Principle Used by Brudzewski for Obtaining the Form of the Cornea.

eye the observer will see the image of the object K_1 in the direction *AE* such that the angle of incidence K_1EX, equals the angle of reflection *XEA*, equals the angle *ECK* which the normal *XC* makes with the visual axis *KC*. Let the symbol ω represent the angle *ECK*. The image of *K* will be seen in the direction *KC* since there is normal incidence. When the observer obtains contact of images it can be said that the distance $EG = y$ is equal to the doubling employed. Knowing y and the angle ω, one can calculate the value of the normal from the expression

$$EC = N = \frac{y}{\sin \omega}$$

In conjunction with Fig. 21 there was deduced the formula that the power at any point, D_C, is given by

$$D_C = \frac{n-1}{N}$$

and therefore we see that

$$D_C = \frac{(n-1)\ \sin\ \omega}{y}$$

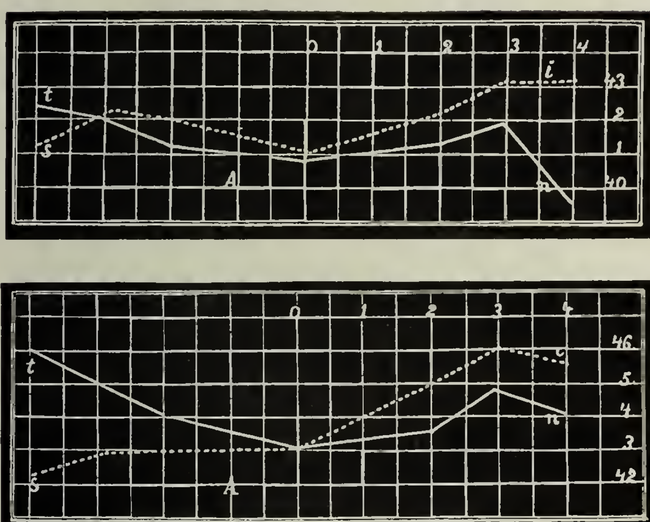


Fig. 23.—Curves Showing the Spherical Aberration of the Cornea. (After Brudzewski.)

The abscissæ indicate the distance from the visual axis in millimeters; the ordinates show the refraction in diopters.

where the angle ω and the distance y must be variable and experimentally obtainable.

46. It is known that a spherical surface has positive aberration. A spherical cornea of 40 diopters has at 4 millimeters from the axis an aberration of about 3 diopters. But such a spherical surface may be made *aplanatic,* i. e., free from aberration and therefore focussing all incident parallel light at a point, if the curvature is sufficiently and properly "flattened out" at the borders. An ellipsoid of revolution which has an eccentricity equal to the inverse of the index of

refraction is such an aplanatic surface. The question which then naturally arises is whether or not there is sufficient flattening of the cornea in the peripheral portions as to correct its aberration. The experimentation of Brudzewski has proven that it is *not;* the aberration is nearly always a positive quantity up to about three millimeters from the axis. Fig. 23 gives some experimental results as to the spherical aberration of the cornea; the abscissæ indicate the distances in millimeters from the visual axis and the ordinates the refraction in diopters. The letter *s* signifies superior, *i* inferior, *t* temporal and *n* nasal regions. The curves of Fig. 23 show a cornea affected but

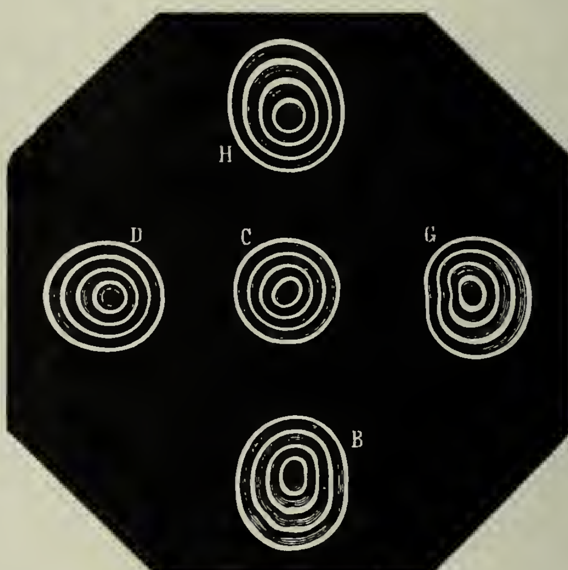


Fig. 24.—Keratoscopic Figures of a Cornea Presenting a Considerable Astigmatism at the Central Part. (After Javal.)

slightly by spherical aberration. The positive aberration is most noticeable temporally and downward. Within a zone lying between the 3 mm. mark and the 4 mm. mark there will always be found a *positive* aberration *temporally* and either "infra" ly or "supra" ly. *Nasally* within this zone the aberration generally becomes *negative.* The maximum amounts of corneal spherical aberration recorded lie between $+ 4.5$ D and $- 2.2$ D.

47. *Examination of the cornea with the keratoscopic disc.* The Placido's disc is a common form of keratoscopic disc; it consists essentially of a circular plate on which is painted alternate rings of black and white. At the center there is a circular aperture or a convex lens

which acts as a simple microscope. When the patient looks toward the center of the disc the images of the circles seen apparently just back of the cornea are, in the normal eye, circles; in an astigmatic cornea they are elongated along the meridian of least refraction. By having the patient look toward the border of the disc it is easy to see and establish the peripheral flattening of the cornea. Fig. 24 presents some keratoscopic figures copied from Javal. *C* represents direct fixation; *H*, upward; *B*, downward; *D*, to the right and *G*, to the left. These figures show that the central part of the cornea (Fig. 24, C) was affected with a pronounced astigmia while the middle zones are

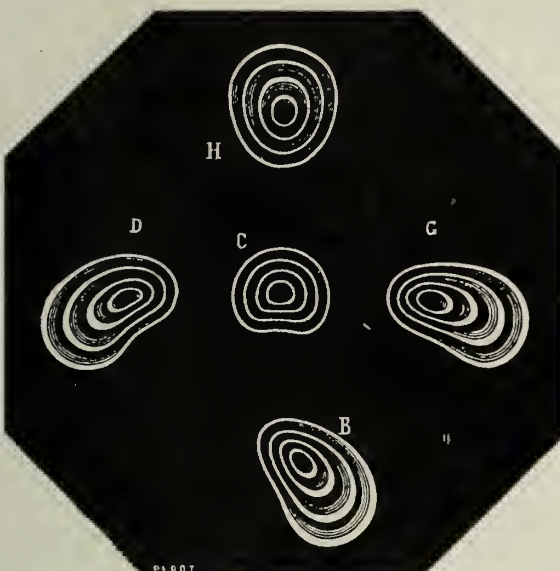


Fig. 25.—Keratoscopic Figures of a Case of Keratoconus. (After Javal.)

scarcely affected at all; in fact the central ring of figure C, which corresponds to the middle of the cornea, is much lengthened while the more peripheral rings are almost circular. The aberration effects at the periphery are noticed in H, G, B and D. In cases of irregular astigmatism the circles assume irregular forms and one may obtain important information from them. Fig. 25 is a reproduction of the keratoscopic figures in a case of keratoconus after Javal. In such cases the image of the disc is small at the summit but a slight deviation of the look causes a change of form by lengthening the image radially.

In Fig. 26 are reproduced the forms of the horizontal section of the cornea according to Cordiale. Curve 1 is for a normal cornea; Curves

II, III and IV for a case of keratoconus. Curve I, for example, is constructed as follows:—the arc *ad* is struck, with its center on the visual line, having a radius corresponding to that which the cornea possesses along the visual axis. A distance is then taken graphically which corresponds to the *normal* at one millimeter on the temporal (T) side; one of the compass points is placed upon *a*, the other is made to fall upon the visual line and the arc *ab* then drawn; the same procedure is followed in obtaining the remaining portions of the curve.

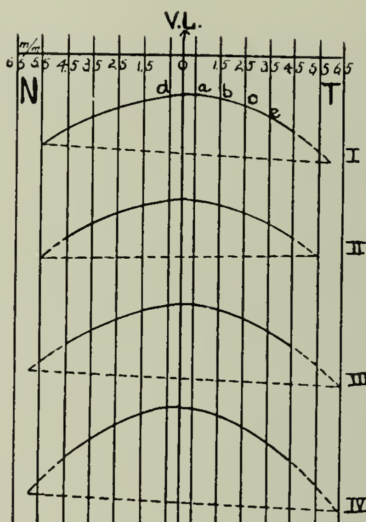


Fig. 26.—Form of the Horizontal Section of the Cornea. (After Cordiale.) Curve I, Normal cornea. Curves II, III and IV, Keratoconus.

48. *The images of Purkinje and ophthalmophakometry.* When a ray of light encounters a polished surface separating two transparent media it will be separated into a reflected ray portion, which will travel back into the first medium, and a refracted ray portion passing on into the second medium. If we represent the incident intensity by unity, then, according to the formula of Fresnel, the intensity (I_{refl}) of the reflected portion will be

$$I_{\text{reflected}} = \frac{1}{2}\left\{\frac{\sin^2(i-r)}{\sin^2(i+r)} + \frac{\tan^2(i-r)}{\tan^2(i+r)}\right\}$$

where *i* and *r* are the angles of incidence and reflection respectively. When the angles are small their values approach those of the sines and

tangents; likewise, it is permissible to write the law of refraction as $i = nr$. Hence, making these assumptions and substitutions in the above equation we have

$$I_{\text{reflected}} = \left(\frac{i - r}{i + r}\right)^2 = \left(\frac{n - 1}{n + 1}\right)^2$$

49. If a flame is placed at some distance from a lens in a dark room two images, one by reflection from each side respectively, will be observed on the same side as the light is situated. If the observations are made on the reverse side, the eye being properly situated, there will be found the dioptric image which is real and inverted, and in addition a small, feeble image due to the double reflection at the internal surfaces of the lens. In Fig. 27, *AB* represents the incident

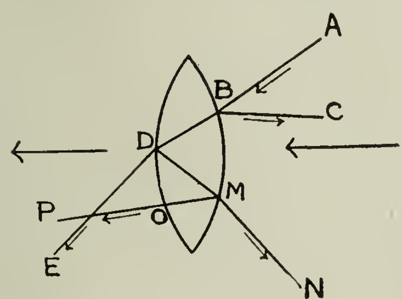


Fig. 27.—Reflections and Refractions by a Lens.

light, *BC* the direction of the reflected ray at the surface *BM*, *DE* the emergent refracted ray, *MN* the emergent ray after one internal reflection at *D* and *OP* the emergent ray after two internal reflections at *D* and *O*. The incident light is thus divided into three parts *visually* considered: (1) the *useful* ray, such as *DE*, which contributes to the formation of the dioptric image, (2) the *lost* rays, such as *BC*, which dissipate energy by reflection and (3) the *harmful* rays, such as *OP*, which cause indistinctness of image. Such harmful rays may indeed enter an eye which is observing the useful image and be a source of disturbance. This term "harmful rays" need not be limited to doubly internally reflected rays for they exist, for instance, in connection with toric or meniscus lenses whose inner surfaces serve as reflectors of light incident from the rear of the eye.

To return to the formula of Fresnel, we find that for a simple lens of index 1.50 there is a loss by reflection of $I_{\text{reflected}} = \left(\frac{n - 1}{n + 1}\right)^2 =$

$\left(\dfrac{0.5}{2.5}\right)^2 = \dfrac{1}{25}$ or approximately 4 per cent. The refracted ray (DB) intensity must then be 96 per cent., which is calculable from the relation $I_{\text{refracted}} = \dfrac{4n}{(n+1)^2} = \dfrac{6.0}{6.25} = 96$ per cent. These figures hold for normal incidence only; in general the loss by reflection is 8 per cent.

For the doubly internally reflected case we find that the percentage of the refracted ray, DB, which passes out at PO as a harmful ray, is given approximately by

$$96\% \times \left(\frac{0.5}{2.5}\right)^2 \times \left(\frac{0.5}{2.5}\right)^2 = 0.16\% = 0.2\% \text{ (app.)}$$

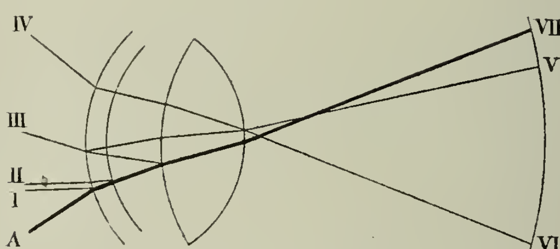


Fig. 28 A.—Manner of Division of Luminous Ray in the Eye. Ray VII is the useful ray.

When these mathematical processes are applied to the eye we can calculate the percentage losses by reflection and refraction at various surfaces. The index of the cornea is 1.377, that of the aqueous is 1.3365; the relative index is 1.03. The relative index of the crystalline with respect to the aqueous is 1.07. There results, then, a loss by reflection of about 2.5 per cent. at the anterior surface of the cornea, as calculated by the Fresnel formula, and a loss at the anterior surface of the cornea of 0.02 per cent. The reflected losses at the crystalline amount to about 0.1 per cent. It is of extreme importance that the losses by reflection at the internal surfaces of the eye are so small. This causes the amount of harmful rays reaching the retina to be reduced to a minimum; but feeble as is this amount it is, nevertheless, sufficient to be visible.

50. The dioptric image formed upon the retina is the useful image for visual purposes: the lost light forms four false images of the first

order, known as the *images of Purkinje,* one for each surface. They correspond to the rays I, II, III and IV of Fig. 28 (A). The harmful rays form a series of false images of the second, or less intense, order, of which only one is visible as V and VI in the figure. Ray VII is the useful ray falling upon the retina.

The positions of the seven images in the eye when the object is situated some 20 degrees below the visual line are shown in Fig. 28 (B).

51. *The images of Purkinje.* The first of these images, that due to the anterior surface of the cornea, is produced by a single reflection. The others are formed by rays which, after having been refracted once or twice, are then first of all reflected and then suffer other refractions before emerging from the eye. Three of these Purkinje-Sansom images,

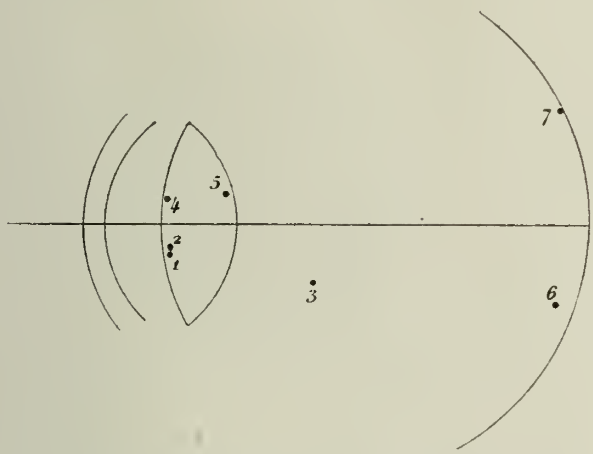


Fig. 28 B.—Positions of Seven Images in the Eye.
Object is assumed to be situated at 20 degrees below the visual line.

as they are often called, can be obtained from a normal eye using an ordinary candle or other luminous source as object. These three images, which are diagrammed in Fig. 29, are due to (1) the direct reflection from the cornea which, acting as a convex mirror, gives an inverted image of the flame situated apparently behind the cornea: (2) the image formed by reflection from the anterior surface of the crystalline lens which acts as a convex mirror giving an inverted image of the luminous object; since the radius of curvature of the anterior crystalline surface is greater than either the cornea or posterior surface of the lens this image will be greater than either of the other two and will be situated the farthest back into the eye of the three named images. This image is the most difficult of observa-

tion excepting that from the posterior surface of the cornea (Image No. 2, Fig. 28 B). Whatever procedure may be adopted for obtaining it, it is always more or less diffuse in appearance due to the fact that the index varies considerably in the superficial layers of the lens. To observe it one must look with care and at just the proper angle; this is usually obtained when the fixation direction of the person examined nearly bisects the angle between the eye of the observer and the luminous object. The image when located presents itself as a broad pale glow and changes position at the least motion of the observed eye. The light can be concentrated on the eye and by this operation the image will soon fill the entire pupil. The pupil frequently appears white and by using a magnifying glass small anatomical defects may be observed. Demicheri reports a case of variously colored zones in

Fig. 29.—Purkinje-Sanson Reflexes.

this image in a case of fairly mature cataract. Tscherning cites a case in which, with the crystalline lens apparently intact, the whole reflex was of an intense red color probably due to interference phenomena arising from the reflections at the finely-ribbed surface of the crystalline. (3) The reflection from the posterior surface of the crystalline; this surface is concave and hence gives an erect image situated somewhere between the two images formed by the two convex surfaces; as a matter of fact it will lie very nearly in the same plane as image No. I. This image (No. 3) is the smallest of the three for the reason that the greater the curvature the smaller the image size. This image usually offers no difficulties to the observer. The clinical value of the Purkinje phenomena lies in the fact that the presence and position of opacities, or absence of the same, may be learned by virtue of the presence or absence of certain of the images.

In Fig. 29, *C* represents the image formed by the cornea, *P* by the

posterior lenticular surface and A by the anterior surface of the crystalline.

52. The optic systems which produce these images are quite complicated, but they can always be replaced by a single refracting surface which Tscherning designates as the apparent surface.

Let us make a study of the system involved in producing the image from the anterior lenticular surface. If one neglects the very weak refraction at the posterior surface of the cornea the rays experience, beside reflection, two refractions, the first on entrance and the second on emergence. This series of refractions and reflections can be replaced by a single reflection at the apparent surface. The position of this surface can be found by finding the position of the image of the real surface, seen through the cornea, by means of the relation

$$\frac{F_A}{f_1} + \frac{F_B}{f_2} = 1$$

The simplified eye, in the calculations which we have previously made, gives 24 mms. as the anterior focal length of the cornea and 32 mms. for its posterior focal length. The depth of the anterior chamber = $f_2 = 3.6$ mms. A substitution of these figures in the above formula gives as the position of the apparent surface, $f_1 = -3$ mms., i. e., three millimeters behind the real surface. It is then possible to find the position of the center of the apparent surface by finding in a similar manner the image of the center of the real surface seen through the cornea; this gives, when $f_1 = 13.5$ mms., the value of $f_2 = -17.5$ mms. The apparent surface then being at 3 mms. and its center at 17.5 mms., it performs the function of a convex mirror of 14.5 mms. radius placed 3 millimeters behind the cornea. Since the focal length of a curved mirror is equal to one-half its radius of curvature, therefore, in this case, the focal length will equal $\frac{14.5}{2} = 7.3$ mms. and the focal point will be at a distance equal to $7.3 + 3 = 10.3$ mms. Hence the Purkinje image from the anterior surface of the crystalline is formed at this point. Since the object used is generally at quite a distance from the eye, the images are formed very near to the catoptric foci of the apparent surfaces. The anterior corneal, the posterior corneal and posterior lenticular images by reflection lie nearly in the pupillary plane, while the image from the anterior crystalline surface is situated about 7 mms. behind this plane.

53. There are two false images referred to as the fifth and sixth images of Purkinje. The fifth is produced by an initial reflection at

the anterior surface of the crystalline lens and a second reflection at the anterior surface of the cornea. The rays (see Fig. 28 A) return toward the retina, hence these images are wholly subjective. The focus of the fifth image is near the posterior surface of the crystalline lens; hence the image of a distant object is formed at that surface. Before reaching the retina the rays are so dispersed that they are no longer visible. The focus of the sixth image, due to a first reflection at the posterior surface and a second reflection at the anterior surface of the cornea, is very nearly on the retina of an emmetrope: the image is generally easily observed subjectively. In a half-darkened room, with a fixation point at some distance away, we give the lamp a to-and-fro horizontal motion, moving it towards and away from the visual line. There will then be noticed on the other side of the visual line a pale image of the lamp. Some people see this image sufficiently distinctly to be able to say that the image appears inverted; the retinal image we know will be erect. The form of the image is most clearly discerned when the object passes below the visual line; the image then passes above and is seen with its apex directed downwards. This shows how fortunate it is that the "harmful" light is reduced to a minimum in the eye, since if it had any appreciable brilliancy all eyes would suffer from monocular diplopia. Calculations show that the sixth image is only about $\frac{1}{40000}$ of the brightness of the useful image.

54. *Point of fixation—Visual line—Optic axis—Angle alpha.* We have used the terms *fixation, visual axis* and *angle alpha* several times in the preceding pages on catoptric images. We shall now pass on to an application of the ophthalmophakometer to the determination of the angle alpha, hence it seems desirable to define the above terms at this point. When an eye *fixes* an object it does so, under normal conditions, in such a way as to place the image of the object fixed upon the fovea. The point fixed and the fovea are, therefore, conjugates. The fovea has an extent of 0.2 mm. to 0.4 mm. or subtends an angle of 0.75° to 1.50° at the posterior nodal point (16 millimeters from the retina). The diameter of the moon subtends at the nodal point of the eye approximately one-half a degree, hence when looking at the sky the fovea would cover an area of about three times the moon's diameter. It is easily possible to tell whether the right or left border of the moon is being fixed; in fact one can generally tell which of two points is being fixed as long as two can be distinctly and separately seen.

55. The *optic axis* is the central line of the globe connecting the geometrical center of the cornea with that of the fundus. It passes

through the center of the crystalline to a point near the inner margin of the macula lutea. According to the commonly accepted definition of the optic axis the anterior pole is the center of the cornea and the corresponding point on the fundus the posterior pole. In Fig. 30, *AB* represents the optic axis with *A* as the anterior and *B* as the posterior poles. We shall have occasion to discuss later on Savage's views as to the optic and visual axes; he believes, in brief, that the posterior pole of an eye should be considered the foveal fixation point with the anterior pole situated as chance may bring it where a line from the posterior point through the center of rotation of the eye cuts the cornea. An exact centering would demand that the four centers of curvature of the four ocular surfaces involved should lie on a straight line. A considerable number of eyes, which are functionally normal, show defects of centering; the most commonly en-

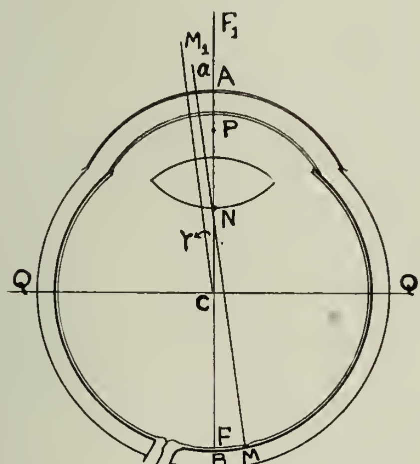


Fig. 30.—Diagram Illustrating Positions of Optic and Visual Axes and Geometrical Significance of Angles Alpha, Gamma and Kappa.

countered defect is that the center of the cornea is situated about a quarter of a millimeter below the axis of the crystalline lens. All have agreed, therefore, to call the optic axis the line which passes through the nodal points of the lens and that the optic system of the eye may be considered as centered around this line.

56. The *visual axis,* or line of vision, passes from the fovea through the nodal point *N* of the crystalline to the point of fixation. Strictly speaking it passes through the first nodal point and after passing into the vitreous proceeds to the fovea as if coming from the second nodal point. Since, in a normal eye, the nodal points are very near the

center of curvature of the anterior surface of the eye, little or no error is introduced by assuming an aphakic eye in which the visual line passes through the center of curvature of the anterior surface. The direction of the visual line is shown in Fig. 30 as MNM_1. It does not depend upon the position of the pupil. The visual line of the eye can be experimentally obtained by methods involving the use of the ophthalmophakometer to be discussed in succeeding paragraphs.

57. Since the fovea is not on the optic axis it follows that the visual and optic axes cannot coincide. The angle M_1NF_1, Fig. 30, formed by these two axes at the single reduced nodal point, N, of the eye is known as the *angle alpha;* the optic axis is on an average directed outward and downward from the visual axis by an amount of 5° to 7°. This is the definition of this angle as given by Donders, Tscherning, Howe and others. As we have seen, the anterior surface of the cornea, being flattened toward the periphery, may roughly be compared to an ellipsoid of revolution; certain authors designate as alpha the angle which the line of vision forms with the axis which passes through the summit of the corneal curve. Generally the axis of the cornea and optic axis coincide, so that these two definitions amount to the same thing. It seems best to retain as a definition of the angle alpha that laid down by Donders, to wit: the angle between the optic and visual axes.

The size of the angle alpha varies, therefore, with the distances MB and MN. If the distance MB is 1.25 mms. (Fig. 30) and that of MN is 15 mms., we find that

$$\sin \alpha = \frac{\mathrm{MB}}{\mathrm{MN}} = .083 = \sin 5°.$$

This is approximately its value for an emmetropic eye; it varies however. In myopia the angle is less than in emmetropia, in fact may be reduced to zero or even be of such a value as to cause the anterior end of the visual axis to fall to the temporal side of the optic axis. In this case the angle is said to be negative. Extreme values may result from anatomical anomalies as to the position of the macula with respect to the posterior pole of the optic axis. In hyperopia, alpha is usually greater than 5° and may be as large as 8°—10°.

The *angle gamma* (γ) is frequently referred to in ophthalmic literature. It is the angle M_1CF_1 formed by the optic axis and the line of fixation at the center of curvature (see Fig. 30). This angle differs but slightly from angle alpha and the two may be considered as equal.

58. *The ophthalmophakometer.* Tscherning has devised an instru-

ment known as the ophthalmophakometer for minutely investigating the Purkinjean images and thereby experimentally determining the centering and decentering of internal surfaces in particular. The instrument consists essentially of a telescope which has a focal length of about eighty-five centimeters; the telescope is suitably mounted on a support. A copper arc is fitted around the axis of the telescope and bears a scale the zero of which coincides with the axis of the telescope. The radius of the arc is about eighty-five centimeters. The purpose of this long radius is to enable the telescope to be placed so far from the observed eye as to make possible the approximate focusing of the

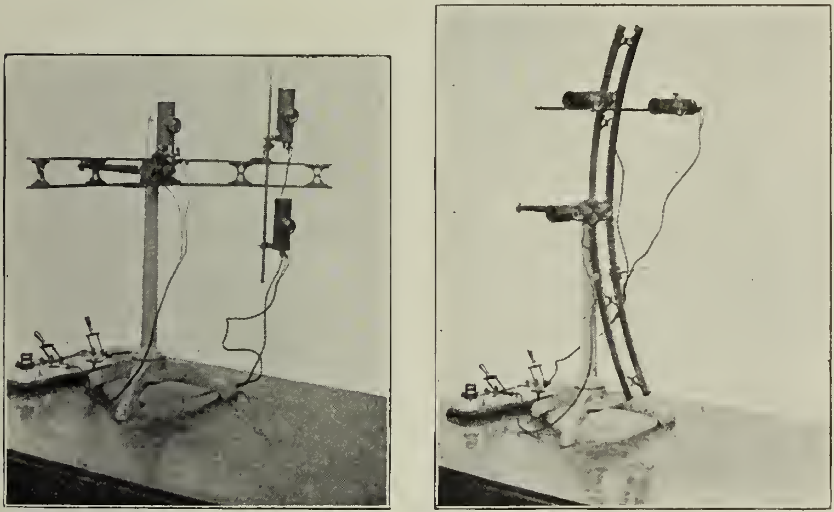


Fig. 31.—Ophthalmophakometer of Tscherning.
By permission of G. P. Putnam's Sons.

reflections from the cornea and the two surfaces of the crystalline at the same time. The arc can also be rotated about the axis by as much as thirty degrees. On the arc move several ''cursors'' or ''carriers'' which are fitted with electric lamps properly screened and carrying in front a convex lens for the purpose of concentrating the light on the eye. The carriers are so arranged that carrier *A* bears one lamp, carrier *B* bears an upright bar having two lamps and carrier *C* has an upright bar carrying a fixation object.

The instrument is shown with the arc horizontal in one of the diagrams of Fig. 31 and vertical in the second.

[The illustrations of Fig. 31 do not carry the letters *A*, *B* and *C*: however, the designation that carrier *A* bears one lamp, carrier *B* two

lamps and carrier *C* the fixation object should suffice to prevent any confusion.]

59. *Measurement of the angle alpha.* The ophthalmophakometer of

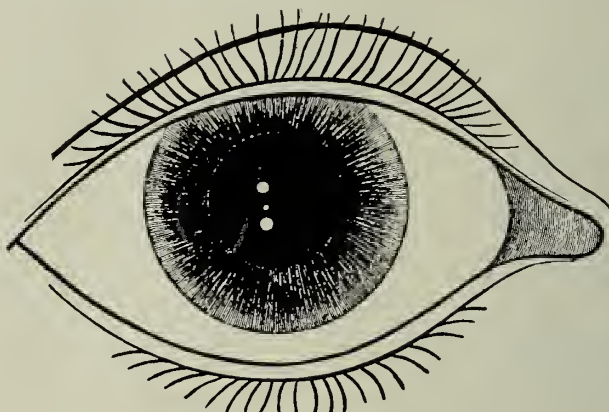


Fig. 32.—The Image of Purkinje observed with the Ophthalmophakometer when the Lens is in Alignment. (After Tscherning.)

Tscherning may be used for the purpose of determining the value of the *angle alpha.* The arc is placed horizontally and the cursor *B* at the zero point of the arc so that its lamps are in the same vertical

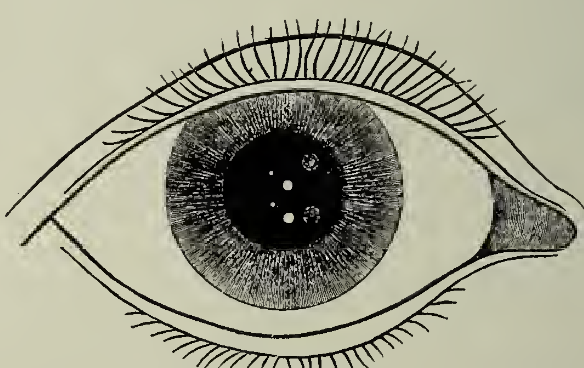


Fig. 33.—Images of Purkinje Observed with the Ophthalmophakometer when the Lens is not in Alignment.

Positions of the images when the observed person looks into the telescope.

plane as the middle of the telescopic objective and the patient is requested to fix the center of the objective. (The lamp and cursor *A*, Fig. 31, are removed in this experiment.) If the surfaces of the eye were all centered around the visual line there would be seen six images

by reflection upon the same vertical line; strictly speaking there should be eight such images but those from the posterior surface of the cornea are not visible under the conditions specified. By regulating the dis-

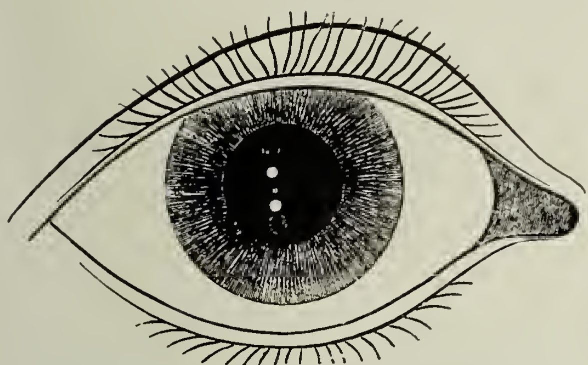


Fig. 34.—Images of Purkinje with the Ophthalmophakometer.

The two lamps B (Figure 31) are in the same vertical plane as the axis of the telescope and the observed person looks at 5.7° on the nasal side, so as to align the images. The optic axis of the eye coincides under these conditions with the axis of the telescope. (After Tscherning.)

tance between the lamps of carrier *B* it should be possible to superimpose the reflections of one of these lamps which come from the anterior and posterior lenticular surfaces upon the reflections from

Fig. 35.—Defect of Centering. It is impossible to align the six images. (After Tscherning.)

the same surfaces due to the other lamp. Hence three images only, all in a vertical row or line, should be obtained if exact centering existed, as is shown in Fig. 32. Such a condition as shown in Fig. 32 has not been found to exist. The images are always seen as depicted in Fig. 33, with the corneal images (*C*) in the middle, those from the

anterior surface of the crystalline (A) on one side and those from the posterior surface of the crystalline (P) on the other side. The patient is then requested to fix the bright ball at the center of the cursor C and this fixation point is slowly moved until the images are seen as shown in Fig. 34. The optic axis is then in the vertical plane passing through the axis of the telescope and the angular distance of the carrier C from the telescope indicates how much the visual axis deviates from the axis in the horizontal plane. This angle can be measured with considerable accuracy. This same method, with the arc vertical and the two lamps in a horizontal plane, gives a determination of the vertical deviation of the visual line. The optic axis is nearly always directed outwards from the visual line and most frequently downwards about 2° to 3°; sometimes, however, it is found in the same horizontal plane or deviated a little upwards.

It is often impossible to get the six images on a straight line. Two pairs can be aligned but the third remains outside. This occurs when the eye is not exactly centered, i. e., when the axis of the crystalline lens does not pass through the center of curvature of the cornea. We can nearly always establish slight defects of this kind, but generally they are negligible. When more considerable defects are found it is generally because the axis of the crystalline lens passes a little above the center of curvature of the cornea. Fig. 35 shows a defect of centering; it is impossible to align the six images.

60. *Ophthalmoscopic and perimetric methods of determining the angle alpha. The clinical value of the angle alpha.* Howe, in his *Muscles of the Eye*, gives as the clinical value of the determination of the angle alpha, the following:—

First. Two methods of measuring it can be made use of, with slight modification, to measure pathological deviations of the eye.

Second. The supposed divergence of some hyperopes can be shown to be only apparent.

Third. A large angle alpha may act as a predisposing cause of pathological deviations.

The easiest method of quickly estimating the size of the angle from the apparent position of the corneal reflex with reference to the center of the pupil is by the use of the ophthalmoscope. Maddox, in his *Ocular Muscles,* devotes a chapter to ophthalmoscopic corneal images and shows how they may be used for the determination of heterophoric and paretic conditions. A full discussion of this subject would lead us astray from our proper domain, however.

When the observed eye looks straight at the small ophthalmoscopic lamp, or at the opening in the center of the mirror, the visual axis

normally passes through the inner side of the observed cornea to the fovea. If the angle be small or of zero value the reflex from the cornea appears in the center of the pupil. If the angle be large the reflex from the cornea will be close to the inner edge of the pupil. In myopes, when the angle alpha may be negative, the reflex may be seen at the outer or temporal edge of the pupil. One must be sure, however, that the pupil is central and normal. Fig. 36, taken from Maddox, shows the ophthalmoscopic reflections in emmetropic eyes; above, (a), when both eyes are looking at the center of the mirror and below, (b), with both eyes looking to the right. These diagrams show a symmetry of the corneal images owing to the angle alpha in the first case, but asymmetry of the images in the second case although the eyes are not squinting.

a.
b.

Fig. 36.—Ophthalmoscopic Corneal Reflections in Emmetropic Eyes. Above, with both eyes looking at the center of the mirror; below, with both eyes looking to the right, showing a symmetry of the corneal images owing to the angle alpha. (After Maddox.)

If one desires to decide whether the patient's squint is real or apparent, it is only necessary to flash the light on first one and then the other eye. If the corneal images occupy symmetrical positions in the two corneæ, no squint exists and the cause of the apparent squint will be made evident from the symmetrical inwards or outwards displacements of the reflexes. Marked unsymmetrical displacement shows the existence of real squint. The method is of special service with very young children, since deviations can be readily detected and the squinting eye located. It can be readily proven that when the corneal reflection of the lamp occupies the margin of a medium-sized pupil (say 3.5 mms.), the amount of squint is approximately 15° to 20°, while if it is situated at the sclero-corneal border it represents about 45° deviation. This affords a rough and ready method of estimating "fixation" conditions.

61. In the *perimetric* method, the right eye of the observed person

supposedly under examination for example, with the head adjusted in proper position in the usual manner, the patient is directed to look at the zero point of the arc. If then a small electric lamp or candle be placed at the zero point and the examiner, sitting in front, sights over this point, the corneal reflex may appear, for instance, to come from the inner or nasal side. If, with the observer still sighting along the zero degree line, the light is moved along the arc to the left of the patient and his eye follows the light, a point will be reached at which the corneal reflex will be in the center of the pupil. The number of degrees traversed is the measure of the angle alpha.

62. *Modification of the Javal ophthalmometer for estimating the position of the crystalline lens.* The axis of the crystalline lens does not in general coincide with the optic or the visual axis. According to Lucien Howe the lens usually faces temporal-ward in relation to the visual axis and its upper edge is generally tipped forward. Such

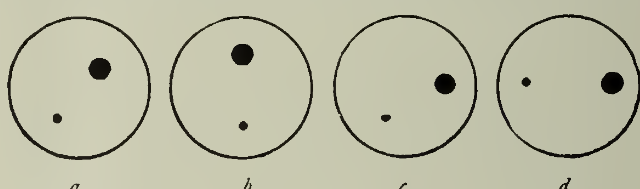


Fig. 37.—Reflections from the Cornea and Posterior Capsula.

(A) When the lens is tipped outward (its usual position).
(B) When the lens is in vertical alignment.
(C) When the lens is tipped forward.
(D) When the lens is in horizontal alignment. (After Howe.)
Permission of G. P. Putnam's Sons.

a tilting or malposition of the lens not only produces in and of itself a slight amount of astigmatism, but may produce conditions requiring considerable traction on the part of the ciliary muscle. The position of the lens may be quickly determined by the relative positions of the corneal and the posterior lenticular reflections, using a candle or other luminous source, as described in connection with Fig. 29. If the observer looks straight into the observed eye and, vice versa, the visual axes of both coinciding and a candle is held slightly above or below the observer's eye, he would see the reflection from the cornea and from the posterior surface of the lens in the same vertical line provided the axis of the lens coincided with its visual axis. But if the lens of the observed eye tilts outward or inward a little, the reflexes will be as shown in Fig. 37 (A). The lens usually faces temporal-ward, hence, if the observed eye is slowly rotated toward the median point, a position will be found when both images will be in a vertical

line as in Fig. 37 (B). Fig. 37 (C) shows that the lens is tilted forward; the observed eye is then turned up or down slowly until the reflexes both stand in the same horizontal plane as in Fig. 37 (D). The measurements of the number of degrees the globe of the observed eye must be turned in any direction to give alignment of images are, of course, only approximate by such methods.

The Javal ophthalmometer may be easily modified to serve as a satisfactory ophthalmophakometer; the essential features of this method are due to Howe. The inner sheath which holds the prism should be removed and an arrangement, in the form of a slot and pin device, made so that the prisms may be quickly removed or inserted. A small electric light is placed about six centimeters below the center of the arc, turning when the arc turns. A conspicuous fixation point is attached horizontally to the top of one of the mires; a hat pin serves this purpose very well. In order to use this instrument as an ophthalmophakometer it is simply necessary to remove the prisms, light the small electric lamp and have the patient look at the fixation object or point placed above the barrel of the instrument as nearly at its axis as possible. The mires of the ophthalmometer are not in anywise serviceable as mires but do serve as a means of moving the fixation point away from the telescopic axis until the point is reached when the corneal and posterior capsular reflections are in line. This method also furnishes a ready means of finding the angle alpha.

63. *Determination of the positions of the internal surfaces.* In his *Physiologic Optics* Tscherning has given methods of using the ophthalmophakometer for determining the positions of the internal surfaces and also the centers of the internal surfaces. He says:—

"I take the anterior surface of the crystalline lens as an example and I suppose that we are making the measurement in a horizontal direction. It is useful to dilate the pupil.

"I place the arc of the instrument horizontally and I place also, as far away as possible from the telescope, the cursor A [see Fig. 31 of this text], the lamp of which must be sufficiently brilliant that the image of the surface to be measured may be quite visible. This done, I place the cursor *C*, which carries the mark of fixation, at a place such that the optic axis of the eye may bisect the angular distance between the telescope and *A*." [Note by C. Weiland, translator of Tscherning's *Physiologic Optics:* "If the eye is not centered we must replace the optic axis by the line passing through the center of curvature of the cornea and the center of the surface which we desire to measure. We find this line by aligning the corneal images with the images of the surface to be measured]. "It is necessary, therefore,

to have previously measured the angle alpha. We then displace the cursor *B,* the lamps of which must be very feeble, so that we may see only the corneal images, until the crystalline image of *A* is exactly on the same vertical as the corneal images of *B.* Glancing at Fig. 38 (this article) it is easy to see that we now possess the elements necessary to calculate the distance of the anterior surface of the crystalline lens from the summit of the cornea, for the angle *c* is half the angular distance of *A* from the telescope, and the angle *d* is half of the angular distance of *B* from the telescope. Supposing that we knew the radius of the cornea R_1, which should have been measured previously, the triangle O_2C_1P [Fig. 38] gives us the relation

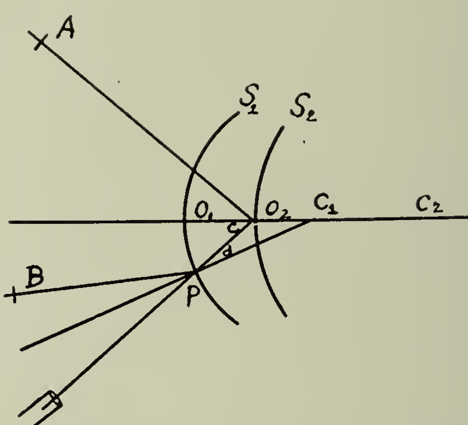


Fig. 38.—Method of Determining the Position of an Internal Surface of the Eye.

S_1, anterior surface of the cornea; C_1, its center; S_2, anterior surface of the crystalline lens; C_2, its center; C_1 C_2, optic axis of the eye. (After Tscherning.)

$$O_2C_1 = R_1 \frac{\sin d}{\sin c}$$

and we have for the distance looked for

$$O_1O_2 = R_1 - O_2C_1 = R_1\left(1 - \frac{\sin d}{\sin c}\right) = R_1 \frac{\sin c - \sin d}{\sin c}.$$

If very great exactness is not desired the sines can be replaced by the arcs.

"Example:—Let the radius of the cornea be 7.98 mm., the distance of A from the telescope 28° nasal, that of B 16.8° nasal; we will have

$O_1O_2 = 7.98\left(1 - \dfrac{\sin\ 8.4°}{\sin\ 14°}\right) = 3.16$ mm. The apparent depth of the anterior chamber would, therefore, be 3.16 mm., whence we find the true value 3.73 mm. by placing in the formula $\dfrac{F_A}{f_1} + \dfrac{F_B}{f_2} = 1$, the values $F_A = 23.64$ mm., $F_B = 31.61$ mm. and $f_1 = -3.16$ mm.''

64. *Determination of the centers of the internal surfaces.* Tscherning writes:—''We place *A* above the telescope and we move *C* with the mark of fixation as far as possible from the telescope, but so that

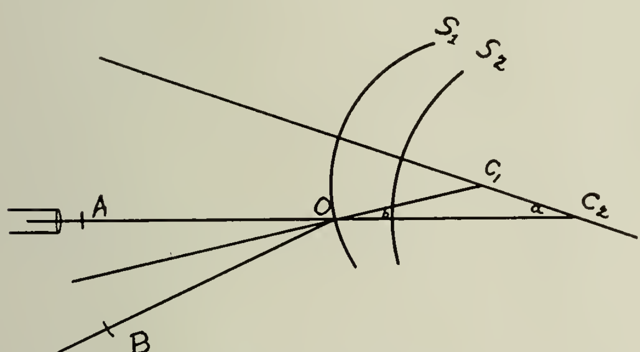


Fig. 39.—Method of Determination of the Position of an Internal Surface of the Eye. (After Tscherning.)

the image may not disappear behind the iris; then we displace *B* until the corneal images of its two lamps are on the same vertical line as the crystalline image of A.

''Under these conditions, the axis of the telescope is perpendicular to the apparent anterior surface of the crystalline lens.'' [Note by C. Weiland, translator: ''If we imagine the lamp placed at the center of the objective, the ray which meets the observer's eye would be reflected exactly on itself, which can take place only if it meets perpendicularly the apparent surface.'']. ''We find the angle *a,* Fig. 39, by adding (subtracting) the angle alpha (α) to the angular distance of *C* from the telescope. The angle *b* is half of the distance of *B* from the telescope; we have

$$C_2C_1 = R\,\frac{\sin b}{\sin a}$$

and the distance sought equal to

$$R_1\left(1 + \frac{\sin b}{\sin a}\right) = R_1\left(\frac{\sin a + \sin b}{\sin a}\right)$$

"Example:—In the same eye as before let alpha = 5.1°, the distance of *B* from the telescope 12.4° temporal and that of *C* from the telescope 9.9° nasal. We would then have the distance sought 7.98 $\left(1 + \frac{\sin 6.2°}{\sin 4.8°}\right)$ = 18.28 mm. and the apparent radius would be 18.28 mm. — 3.16 mm. = 15.12 mm. The position of the real center would be 13.78 mm." [Note by C. Weiland, translator:—"Considering that we have again obtained this apparent position with reference to the refraction of the cornea, we must, therefore, in the formula $\frac{F_A}{f_1} + \frac{F_B}{f_2} = 1$ put $F_A = 23.64$; $F_B = 31.61$ and $f_1 = -18.28$ mm.: this gives $f_2 = 13.78$ mms."] "The radius of the real surface is 13.78 mm. — 3.73 = 10.05 mms."

Ophthalmometry finds daily use in offices and clinics; the methods of measurement of the internal surfaces could hardly find such application. There are certainly differences between astigmatic findings as determined by the ophthalmometer, the retinoscope and subjectively by the trial case and these differences might possibly be explained if we knew more of the conditions present at the various internal surfaces. Tscherning has probably done more with his ophthalmophakometer than anyone else and frankly says that the methods and calculations, even when simplified or approximated, are too laborious, uncertain and complicated; likewise, it is not probable that the explanation of the differences between ophthalmometric and subjective astigmia would be discovered. These differences are possibly due to the fact that the peripheral parts of the cornea have an astigmatism different from that of the central parts which are measured with the ophthalmometer. But the ophthalmophakometer has served to throw much light upon the problem of the mechanism of accommodation.

PART TWO

MONOCULAR VISION AND METHODS OF OBJECTIVELY AND SUBJECTIVELY INVESTIGATING IT

VI. REFRACTIVE ANOMALIES

65. *Emmetropia and ametropia.* Two conditions must be fulfilled in order that the human camera may afford its possessor vision. The perceptive and receptive surfaces must be a mosaic, the individual parts of which can be stimulated by luminous rays, and this stimulation must be carried to the brain without affecting or interfering with the other parts of this surface. There must be a healthy, functioning retina to receive the image; but the dioptric apparatus must collect portions of the light emanating from an object and unite them as an image on this perceptive surface. Perfect vision is almost as impossible of definition as it is in actuality; certainly the prime requisites are perfect focus of image and perfect retinal reception and mental interpretation by the brain. Thus far the eye has been considered as an optical instrument possessed of various dioptric and catoptric media having certain properties, characteristics and constants; we have considered it in a general way (at least mathematically) as a perfect optical device. Such it would presumably be if we excluded chromatic and spherical aberrations which are, under normal conditions, of second-order effect ocularly considered, provided it fulfilled the criteria which have been deduced for the "reduced eye" in the earlier pages of this article. Yet it would not do to say that all eyes that measure, for example, just 23 mms. in their antero-posterior diameter are emmetropic, for while an eye may possess that length it may have a refractive system stronger or weaker than is consistent with its length. Again, the cornea, aqueous and lens may be possessed of such optical curves, indices, powers and what not as to cause parallel light to focus at a point 23 mms. behind the cornea, but the screen, the retina, may be ahead of or behind this point. From the standpoint of vision, therefore, all eyes may be included within two classes, *emmetropic* and *ametropic.* Emmetropia literally means an eye in measure, or an eye which has reached such a state of development that parallel rays of light will be focused upon the retina without any effort of accommodation: the static refractive power is proportional to the axial length of the globe. Ametropia means an eye "out of measure." An eye which is not emmetropic is ametropic; such an eye, in a *state of rest,* does not receive a distinct image of distant objects upon its retina.

There are two forms of ametropia—axial and curvature. In *axial* errors the dioptric apparatus refracts equally in all directions, but the retina of the eye, when at rest, is either closer to or farther away from the nodal point than the principal focus. In myopia this image is formed in front of, and in hyperopia behind, the retina. The first of these is commonly spoken of as the long eye, the second as the short or flat eye.

Curvature ametropia, in contradistinction to axial ametropia, is the condition due to the dioptric apparatus producing unequal refractive effects in different meridians, with the result that there is no focusing of all the rays at one point. It may be considered as that condition in which parallel rays of light entering an eye have two focal planes for two principal meridians usually at right angles to each other; this is commonly known as *astigmatism*. Strictly speaking the above limitation upon curvature ametropia should not be, because myopia and hyperopia may be due to curvature defects and in such a case as that reported by v. Reuss, in which a myope had a corneal curvature of 6.5 mm., there is no doubt but that a portion, at least, of the short-sightedness was due to curvature ametropia. But thus far experimentation has not disclosed a definite relation between refractive status and corneal curvatures and in a majority of cases myopia and hyperopia are due solely to an anomaly in the length of the eye.

There is in addition to axial and curvature changes, as causes of ametropia, the possibility of *indicial* anomalies. Up to the present time the only authentic cases in which anomalies of the indices have been established and which we have been able to find a record are those reported by Demicheri and designated by him as false lenticonus. The refraction at the middle of the pupil was myopic to an amount of 10 D. or more while the peripheral portions showed 3 to 4 D. of hyperopia. The cause of this marked change must, without doubt, be attributed to a diminution in the index of the peripheral layers of the crystalline lens. Such a change would produce a diminution in the refraction of the peripheral portions and greatly increase the central refraction.

66. *The far and near points in emmetropia and ametropia.* All definitions have been made to center around the meaning of the term *emmetropia*. This was stated to be that condition of the eye in which, in a state of repose, infinity and the retina were conjugate points. Infinity is then the fixed fiducial point in emmetropia; it is the far point or *punctum remotum*. One of the most important points to remember in visual optics is that the refractive power is a definite fixed quantity for any given pair of conjugate focal distances. If the

one conjugate is fixed, the other is nearer as the refracting power is greater, and farther away, in turn, as the power is smaller. The point of vision is always the conjugate focus of the retina, otherwise clear vision is impossible at that point. Whatever, then, may be the process and precise mechanism of accommodation the result is always a positive action causing an increased total refractive power of the eye. When the accommodation is totally relaxed the eye is in a condition of minimum refraction and is adjusted for its far point. When, however, the accommodation is totally exerted, the refractive condition of the eye is at its maximum and is adjusted for its near point or *punctum proximum*. The distance between the far and near points is termed the *range of accommodation* and is expressed in terms of linear measure. If the far point (R) is 100 cms. and the near point (P) is 10 cms., then $R - P = 90$ cms. is the range of accommodation. The quantity of accommodation possessed is termed the *amplitude of accommodation*. It is expressed in diopters, so that the amplitude is found from the equation

$$(1)\quad A_D = P_D - R_D \text{ (in diopters)}$$

This equation is frequently written (for example in Donders' *Accommodation and Refraction of the Eye*) as

$$(2)\quad \frac{1}{A} = \frac{1}{P} - \frac{1}{R}$$

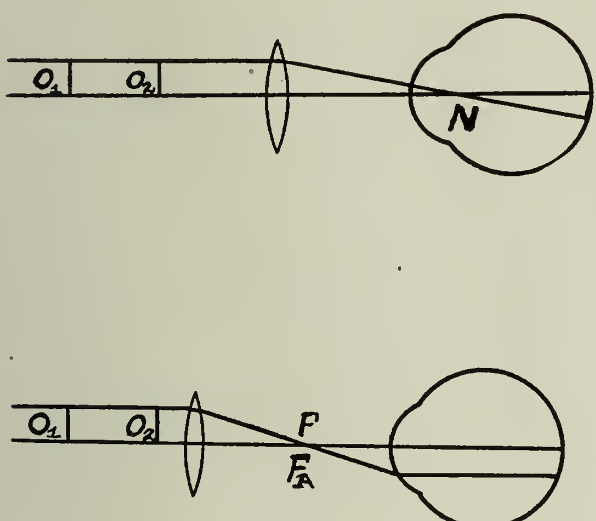
The two equations are identities, for in equation (2) P and R represent linear distances the reciprocals of which represent dioptric power; that is, if the far point is 25 cms. then $R_D = 4$ D.

It is, indeed, the distance of this farthest point of distinct vision from the eye, determined of course by clinical methods and standards, which affords the simplest and most rational method of defining and measuring the degree of ametropia. For one need no longer consider whether the axial length is too long or too short for the static refractive power or vice versa, but may define them as follows: The far point of an *emmetropic eye* is at infinity. In *hyperopia*, the static refraction is deficient so that only convergent light incident on the cornea will focus at the retina with the accommodation inactive; its remote point is, in other words, virtual, situated back of the eye and its distance is to be put down as negative. Thus a hyperope of 2 D. lacks two diopters of static power; he has only 48 D. of static power if we assume that an emmetrope possesses 50 D. power; hence in the above case of hyperopia light must converge to 50 cms. behind the cornea in

order to be focused upon the retina. The punctum remotum in this case is designated as a negative distance. The extra 2 D. of power necessary to render the eye emmetropic must be supplied by a + 2 D. lens close to the cornea or by the exertion of 2 D. of accommodation. *Myopia* is that condition in which there is an excess of static power so that only light divergent from a near object can focus at the retina. Thus a myope of 3 D. has an excess of 3 D. static refraction and therefore light must diverge from a point 33.3 cms. in front of the eye in order to focus on the retina. The punctum remotum is, in this instance, positive and a — 3 D. lens placed near the cornea reduces the static refraction by 3 D. and hence renders it emmetropic. Parallel light refracted by the lens then apparently diverges from the 33.3 cm. point which is the far point in this particular case.

67. The determination of the far point can be done readily and with considerable accuracy; not so with the *near point,* however, which depends upon an effort of the patient and which may vary somewhat from day to day and with the patient's general health and nervous vitality. The commonest (and possibly most inaccurate) method is to employ No. 2 Jaeger type, which a person should normally, unless presbyopic, be able to read at 12 or 13 inches, and approach this toward the eye, its mate being covered, until the nearest point is reached at which it is clearly seen or can be read. This distance from the eye to the chart is the punctum proximum. In a case of emmetropia this distance, when reduced to diopters, gives the amplitude of accommodation. This method in ametropia, however, gives only the *apparent* or *available* and not the true amplitude. Likewise it may not be available in presbyopic conditions since the near point may have receded so far that fine print is not readable; in such a case, however, a plus or convex lens may be furnished to assist the patient and bring the near point to a measurable distance, finally deducting this lens from the dioptric value found. In ametropic cases the practitioner will be saved considerable time and trouble if he supplies the patient with the correction for the refractive error statically determined at infinity first of all, since then presumably the far point is at infinity or approaching it as closely as conditions, both pathological and non-pathological, will permit. The eye is then emmetropic (or as nearly in such a condition as circumstances will permit) and the procedure in determining the amplitude of accommodation is the same as that for emmetropia. This method, i. e., the nearest point at which fine print can be read, is open to objection on the basis that the normal reading distance is about 13 inches on an average and the function of accommodation, hence its amplitude, should be tested at this point and no

other. Incorrect accommodative amplitudes from near point determinations are obtained due, the writer believes, to two factors chiefly; (1) there is a more rapid increase of the visual angle than of the circles of diffusion, hence the person under test is able to read at a point nearer than that at which accommodation is still being proportionately enforced, and (2) the reduction in the size of the pupil, which in turn lessens the size of the circles of diffusion. These same reasons explain why, in cases of high hyperopia, small objects can be seen better, or fine type read, nearer the eye than at some distance from it, thus resembling a myopic condition.



Figs. 40, 41.—The Badal Optometer.

Showing the coincidence of the focal point of the lens with the nodal point of the eye.

Showing the coincidence of the focal point of the lens with the anterior focal point of the eye.

68. A great many optometers and punctuometers have been devised but most of them suffer from the errors enumerated above when operated at the near point. Badal's optometer has, in part at least, removed these objectionable features. If a lens, Fig. 40, is placed so that its focal point F coincides with the nodal point of the eye, a ray which is parallel to the axis before refraction passes after refraction by the lens through N, the nodal point, without further deviation no matter what the distance of the object may be. Hence the angle under which the image is formed is always the same and there is no sense of

change as the distance of the test type is increased or decreased. If the lens is placed so that F coincides with F_A, the anterior focal point of the eye, then a ray parallel to the principal axis of the lens, before refraction, is parallel to the principal axis of the eye after refraction. The refraction and apparent amplitude of accommodation of the eye are measured with equality of size of retinal image and the sense of nearness eliminated. A commonly used combination is a + 10 D. placed 115 mms. from the cornea (Fig. 41) or about 90 mms. for the conditions diagrammed in Fig. 40.

The Scheiner disc is a classic device for determining the nature and amount of ametropia, and also of determining the near point. It consists of an opaque disc with two very small apertures separated from each other by less than the diameter of the pupil of the eye under examination. Light from a constricted source at infinity enters the eye and if the eye is emmetropic the two images which are formed will coincide upon the retina and one image only will be seen. When ametropia exists two images will be seen and their location and character indicate the kind of error; in order to specify images it is customary to cover each aperture with a differently colored glass, such as red and green. If the eye is hyperopic, the two cones of light reach the retina before uniting; the right and left cones fall on the right and left sides of the retina respectively, forming two images which are uncrossed but which, according to the laws of projection, will be seen in space as crossed. In myopia the two images coincide in the vitreous and therefore fall upon the retina as crossed images; the projected images are then uncrossed. The punctum proximum is found by holding a thin object, such as a pin, at right angles to the plane of the apertures. It is then approached until a point is found at which the accommodation fails to give union of images and the object is seen double; the nearest point at which a single object only is seen is the near point.

69. A very satisfactory method of determining the *amplitude of accommodation* in practice is to employ *concave lenses*, each eye being tested separately. Briefly, No. 2 Jaeger type should be used at 13 inches; the patient should wear the full distance correction (particularly the cylindrical element, if the spherical member is omitted and afterward taken into the final accounting) and the maximum amount of concave lens power added, step-by-step but quickly, until the patient is unable to continue reading. Some allowance, best of all taken care of by using slightly higher numbers of Jaeger type such as No. 4 for example, should be made in cases of considerably reduced visual acuity and in old age. If full distance correction is worn, then the ampli-

tude of accommodation is quickly formed by adding the maximum concave lens value used (expressed of course as a positive quantity representing so much accommodative effort) to the three diopters of accommodation demanded when reading at 13 inches. For example, if No. 2 type is barely readable through a —4 D. lens at 13 inches, the eye being emmetropic, the amplitude of accommodation would be 7 diopters. This method has the objection that concave lenses cause a diminution in the apparent size of the object, hence this method will give a minimum rather than a maximum value of the monocular accommodation and will accordingly give values of about one-half to one diopter less than those given in the Donders' table of changes in the amplitude of accommodation with age.

The amplitude of accommodation, either monocularly or binocularly, may be obtained *objectively* after the manner illustrated in Figures 41 (B) and 41 (C) taken from Sheard's "*Dynamic Ocular Tests.*" The essential optical principles underlying these tests are those involved in skiametry and the applications of the laws of conjugacy of foci. If the subject under test, either naturally or artificially rendered emmetropic for distance, should fix and read fine print at any close point, then optically the retina and the point fixed should be conjugate points. This is, however, the mathematical ideal condition, demanding and supplying one diopter of accommodative innervation for each diopter of lenticular change. If such ideal conditions hold, then the observer's nodal point, situated just back of the retinoscope and the card of letters attached to the side of the retinoscope, would be practically in the same plane and a neutral reflex or shadow would be skiascopically obtained. These conditions, however, assume the presence of a true or artificially produced emmetropia and a perfectly innervated and functioning ciliary and lenticular action. But in practice it will be found commonly that when the subject, wearing the full static corrections, reads monocularly letters—these letters may be arranged in a vertical row on a narrow, i. e., about an inch wide, card, which can be approached toward the eye from the nasal side, the operator following with the retinoscope from the temporal side—there is a hyperopic motion indicating that the optical conjugate to the retina is somewhat farther from the eye than the point apparently fixed or observed. If now the line of letters (or a pencil will serve the purpose for a rough test) is moved slowly by the subject toward his nose, while the observer keeps his retinoscope fixed in a given position, the operator will notice that the shadow changes from "with" to "neutral" to an "against" motion if a plane mirror is used. Hence the subject's *actual* point of optical conjugacy of retina with respect to the observer's

nodal point may be made to change in such a way that the observer will be, in turn, inside of, just at, and outside of the point of optical conjugacy. In testing, therefore, for the near-point objectively, we proceed as follows: the patient draws the test object toward the eye from about the ten-inch point ordinarily. To the observer at thirteen inches the retinoscopic reflex will show, let us assume, an "against" or myopic condition indicating that he is outside of the optical ocular far-point dynamically considered. The practitioner then moves forward until he obtains the neutral shadow position. The test object is then to be carried still closer to the eye (blurred image as reported possibly by the patient makes no difference) and the nearest point of neutral shadow found and measured. This gives the *apparent* near-

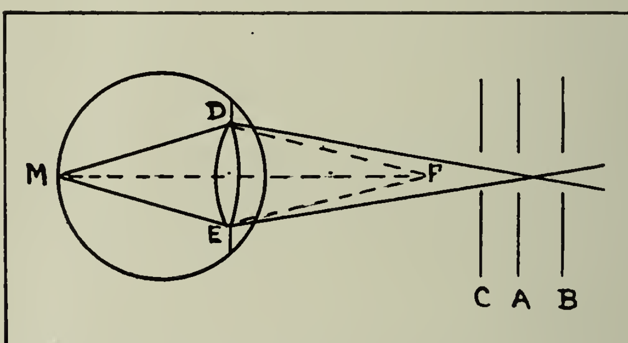


Fig. 41 B.—Illustrating the Optical Principles Involved in the Objective Monocular Test upon the Accommodative Amplitude. (From Sheard's *Dynamic Ocular Tests.* Courtesy of the Author.)

point under whatever ocular conditions the test is made (ordinarily when wearing the distance correction) and from it the range and amplitude of accommodation are easily determined. It is to be noted that the distance *DA* and *not FD* (Fig. 41 B) is to be measured. In Fig. 41 (B) the point *A* is taken to illustrate the optical near-point of the eye, while *F* represents the point at which the eye may be endeavoring to look. The points *C, A* and *B* represent, therefore, positions of the observer with a plane mirror to obtain "with," "neutral" and "against" motions of skiascopic reflexes.

The element of convergence, i. e., binocular single vision, where possible, enters into the problem of the *binocular* amplitude of accommodation. Hence, marked differences in the values of the objectively obtained binocular and monocular near-points are nearly always indicative of disturbances in the extrinsic muscles, or their innervations, or

the supplementary convergence. For the functions of accommodation and convergence ought to be so so-ordinated as to permit of binocular single vision and clearness or distinctness of vision. The *modus operandi* in the binocular accommodative amplitude test is the same as in the monocular test and involves the obtainance of the closest point of neutral shadow. Such binocular procedures throw considerable light upon the problem of the clinical importance of the difference between binocular and monocular near-points.

70. The accommodation has the same effect as a convex lens added to the eye. Let us suppose an eye devoid of all accommodative power;

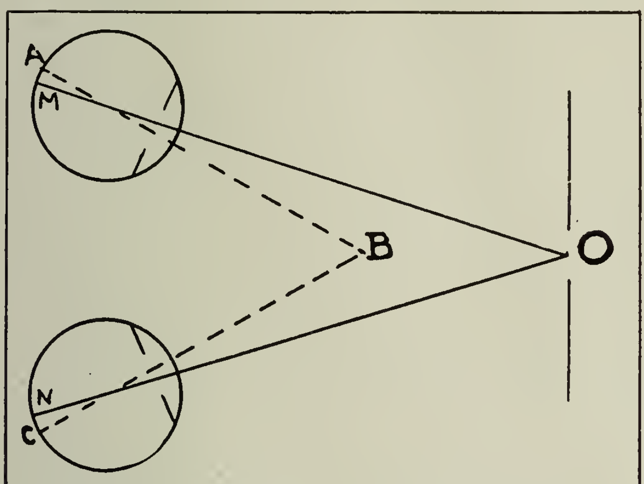


Fig. 41 C.—Illustrating the Optical Principles and Procedure in the Objective Binocular Tests upon the Accommodative Amplitude. (From Sheard's *Dynamic Ocular Tests.* Courtesy of the Author.)

it will not be able to correctly focus anything inside its far point (R); for example, the object M, Fig. 42. To make vision at M possible, the divergence of rays coming from M must be diminished until they have such a direction as will make them appear to come from the point R to which the eye is adapted. If M is the punctum proximum of the eye, the lens which makes vision at the distance HM possible has, therefore, the same effect as the accommodation. The analogy between the effect of accommodation and a convex lens is all the more complete as the seat of the accommodation is in the crystalline lens; to be exactly comparable to the amplitude of accommodation, however, the lens ought to be placed within the eye. In reckoning its focal distance, then, we take as a starting point the cornea or, strictly speak-

ing, the first principal point of the eye. In order, therefore, that the true ametropic error in any case be known the correcting lens must be near enough to the eye that the two may be regarded as united. A consideration of Fig. 43 will aid in making these mathematical statements clear and apparent. Let the distance RH from the far point to the eye equal 50 cms. If we place the correcting lens at a distance $OH = 10$ cms. from the eye then, since $RH - OH = OR$,

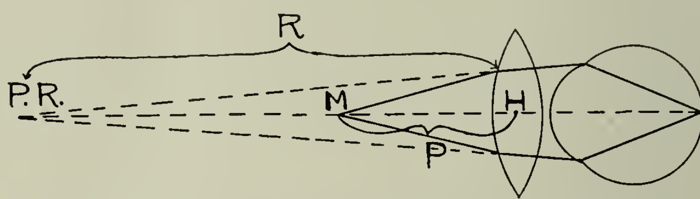


Fig. 42.—Illustrating the Optical Equivalence of Accommodation.

the focal length of the concave lens necessary to correct the real myopia of 2 D., when placed at the point O, will be $50 - 10 = 40$ cms. or -2.5 D. In practice the correcting lenses are generally placed at about 15 millimeters in front of the first principal point, or 13 millimeters in front of the cornea. If the punctum remotum of a certain eye be 125 mms. it would be said to be myopic 8 diopters. But the correcting lens, placed 15 mms. in front of the eye, will need a focal

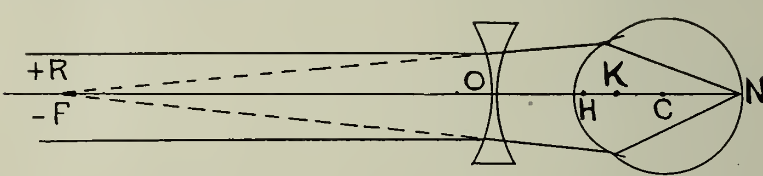


Fig. 43.—Diagram Illustrating the Optical Value of the Lens Needed to Correct a Specified Amount of Myopia; the Lens Being in Advance of the Cornea.

length of $125 - 15 = 110$ mms., or practically a -9 D. lens. This difference between the degree of myopia and the correcting lens becomes greater in proportion as the punctum remotum is nearer the eye. For example, a concave lens of 18 D. placed at a distance of 15 mms. corrects the myopia of a certain eye. The lens has a focal length of -55 mms., hence the punctum remotum of the eye is at $55 + 15 = 70$ mms. and this gives as the true myopic error $^{1000}/_{70} =$ 14.28 D.

71. In cases of hyperopia, however, since the far point is negative or virtual, the exact degree of hyperopia may be determined if allow-

ance is made for the distance between the glass and the eye. In fact, at whatever point a convex lens is placed in front of an eye, it is always possible to find one whose focus coincides with the far point of such an eye. It will cause parallel light to converge toward this point and will correct the hyperopia by enabling the eye to focus such rays upon the retina. Suppose an eye, Fig. 44, to have a punctum remotum at R such that $HR = 111$ mms. behind it. It has, therefore, a hyperopia of $1000/111 = 9$ D. If we place the correcting lens immediately in contact with the cornea, practically at H, this lens must have a power equal to 9 D. But if we place it at 15 mms. farther from the far point, $-R$, it must then have a focal length equal to $OH + HR$, or $111 + 15$ mms. $= 126$ mms. representing a refractive power of 8 D. It is to be noted that from a strictly accurate, scientific standpoint all measurements should be made from the principal point H which is practically 2 mms. back of the cornea. When, for example, we refer

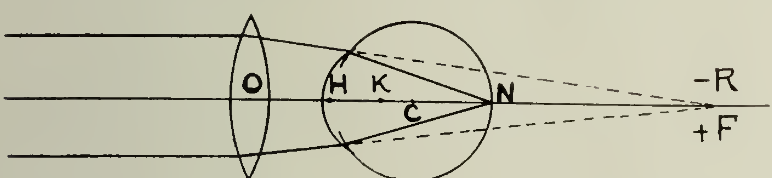


Fig. 44.—Diagram Illustrating the Optical Value of the Lens Needed to Correct a Specified Amount of Hyperopia; the Lens Being in Advance of the Cornea.

to a correcting lens placed 15 mms. from the cornea, the calculations should be made using 17 mms., the measurement of the distance from the principal point of the reduced eye to the position of the second principal plane of the correcting lens. Since the principal planes of a lens are dependent for their location upon the form and thickness of a lens (a subject which is properly treated under **Lenses and prisms, Ophthalmic**) our calculations are pertinent only to lenses which are thin bi-concave or bi-convex in form. The vertex refraction system, so-called, is the only correct method of applying lens corrections having the same power ophthalmologically, whatever the nature of the surfaces or thicknesses of the lens. This system, introduced we believe by von Rohr, of Jena, and proposed in his book, *Das Auge und die Brille,* is simplicity itself and is found from the back focus of a lens; it is independent of the shape of the lens and is based on the only factor which, in connection with the distance of the lens from the eye, is of significance in obtaining the correction. Two simple formulæ give the thin lens equivalent power of a thick lens and the vertex refraction thereof. These are:

$$(A)\ D = D_1 + D_2 - \frac{d}{n} D_1 D_2 \text{ and}$$

$$(B)\ D_V = D \times \frac{1}{1 - D_1 \dfrac{d}{n}}.$$

Equation (A) gives the dioptric power of a lens having dioptric curves of powers D_1 and D_2, of thickness d and index n. Equation (B) gives the vertex refraction D_V in terms of the dioptric thin lens power D and the power, D_1, of the side of the lens nearest the eye. The following brief table gives the vertex refraction of the correcting lens when placed at 13 mms. from the vertex of the cornea of an eye possessing the axial refraction stated in diopters.

Myopia		*Hyperopia*	
Axial Refraction in Diopters	Vertex Refraction of Correcting Lens	Axial Refraction in Diopters	Vertex Refraction of Correcting Lens
— 0.50	— 0.50	+ 0.50	+ 0.50
— 1.00	— 1.00	+ 1.00	+ 1.00
— 1.50	— 1.55	+ 1.50	+ 1.45
— 2.00	— 2.10	+ 2.00	+ 1.95
— 2.50	— 2.60	+ 2.50	+ 2.40
— 3.00	— 3.15	+ 3.00	+ 2.90
— 3.50	— 3.70	+ 3.50	+ 3.30
— 4.00	— 4.25	+ 4.00	+ 3.75
— 5.00	— 5.40	+ 5.00	+ 4.70
— 6.00	— 6.60	+ 6.00	+ 5.50
— 7.00	— 7.80	+ 7.00	+ 6.40
— 8.00	— 9.10	+ 8.00	+ 7.20
— 9.00	—10.30	+ 9.00	+ 8.10
—10.00	—11.80	+10.00	+ 8.80
—11.00	—13.30	+11.00	+ 9.50
—12.00	—14.50	+12.00	+10.30
—13.00	—16.00	+13.00	+11.00
—14.00	—17.5	+14.00	+11.70
—15.00	—19.1	+15.00	+12.4

72. The terms far point and near point and methods for their determination have been briefly reviewed in the preceding paragraphs.

It is of importance to note once more that these measurements give the apparent or manifest refractive condition and the differences, dioptrically expressed, give the amplitude of accommodation. The far point can be, in turn, found from the value of the distance correction lens; in fact this is the general procedure in practice, after which the near point, with or without the distance correction as circumstances may demand, is found. Several illustrative examples will not be out of place. Suppose the near point is at 20 cms. (= 5 D.) and that the eye should be respectively hyperopic 2 D., emmetropic and myopic 2 D. The amplitude of accommodation is desired. Then in

Hyperopia 2 D, $A = P - R = 5 - (-2)\ D = 7\ D$
Emmetropia, $A = P - R = 5 - (O)\ D = 5\ D$
Myopia 2 D, $A = P - R = 5 - (+2)\ D = 3\ D.$

When, then, an ametropic condition is fully corrected, the near point shows the actual amplitude of accommodation provided we accept the validity of the ordinary near point tests. This means, for example, that if a hyperopia of 2 D. is corrected by a + 2 D. S., then the determination of the near point, the patient wearing his ametropic correction, gives the full available accommodation. If then the person under test wears full ametropic corrections he may be considered practically emmetropic refractively and accommodative tests, by near point or concave lens methods, give data upon the available amplitude. An uncorrected hyperope is under constant accommodative strain, an emmetrope exercises accommodation inside of infinity while a myope does not accommodate outside of his far point, which point is always at a finite distance. An emmetrope, therefore, whose near point is at 12.5 cms. has a range of accommodation of 8 D. Suppose a hyperope has the same near point, what is his accommodative amplitude? Since his far point is negative, the accommodation will need to act to make the image due to parallel light focus upon the retina and then proceed to focus from infinity down to the near point. The far point must, therefore, be known. Suppose he is a hyperope of 3 D. The near point is assumed to be at 12.5 cms. This person is possessed of 8 + 3 = 11 D. of accommodative power. If the far point is within infinity, at 50 cms. for instance, while the near point is at 8 cms., the eye will accommodate only within the 50 and 8 cm. points; this gives as an amplitude of accommodation 12.5 — 2 D. = 10.5 D.

73. The *reserve accommodation* is the difference between the total accommodation available in diopters and that needed at any specified point, usually the reading distance of about 13 inches. If a person under test develops 6 diopters of accommodation in toto, while in

daily practice his nearest work is at 20 inches, thus requiring normally the exertion of 2 D. of accommodation, the reserve would amount to 4 D. If this person should read at 13 inches, requiring 3 D. of accommodative action, the reserve at this point would amount to 3 D. It has been generally agreed that, for comfortable and satisfactory working conditions, at least *one-third of the total available accommodation must be kept in reserve.* When such a reserve is not found present, whether due to age or disease, such as diphtheria, scarlet fever and measles, which temporarily or permanently impair the accommodation, the condition may be classed as one of presbyopia, premature presbyopia or subnormal accommodation.

The term *presbyopia* means "old-age sight"; by strict definition such is the case and it can be defined as that condition in which, on account of increased years, additional convex power is required for near vision. It may be defined, however, as that condition in which the near point has receded beyond 22 cms. or 9 inches or when the amplitude of accommodation is below 4.5 D. In a normal condition the strength of the Mueller's muscle, to which the accommodative changes are to be chiefly if not wholly attributed, varies with the age of the patient until advancing years cause it to lose practically all power. The recession of the near point is due, then, to a weakening of the Mueller's muscle and to a general loss of lens elasticity. The refractive power of the eye at rest does not change much, according to Donders, until the age of 55 years. The positive punctum remotum recedes from the eye and R_D becomes less; the negative punctum remotum of the hyperope comes nearer to the eye or $-R_D$ increases. The emmetrope commences to get hyperopic (acquired hyperopia and presumably not an axial or curvature condition at all), the myope notices a decrease in his myopia proportionate with the recession of the far point and the hyperope experiences an increase in his hyperopia. This decrease in the static refractive power of an eye is independent of the nature of the refraction. It affects the hyperope or myope in the same degree as the emmetrope.

Fig. 45, following Donders, shows the course of accommodation in an emmetropic eye. The figures at the top indicate the age; those at the side the amount of accommodation and the near point (P.P.) in centimeters; the oblique line *PP* represents the course of the punctum proximum and the horizontal line *RR* that of the punctum remotum. This diagram presents what may be considered a fair average of accommodative amplitudes for an emmetrope; it is not, of course, to be implicitly relied upon but serves rather to give an average value. The values given in the accompanying figure are probably too high; other determinations and sets of curves have been given by Risley, Duane,

Jackson and others. In the curve *RR*, shown in Fig. 45, it will be noticed that the line begins to deviate downwards at an age point of 50 to 55 years; this indicates that the refraction begins to diminish, i. e., an emmetrope becomes hyperopic. In the case of myopia the curve *RR* is exactly the same as for emmetropia; the diminution of static refraction is the same; only the position of the punctum remotum in the two cases is not identical. The curve *RR* is bodily shifted into the positive portion of the diagram (since myopia represents an excess of refractive power optically considered) by an amount equal

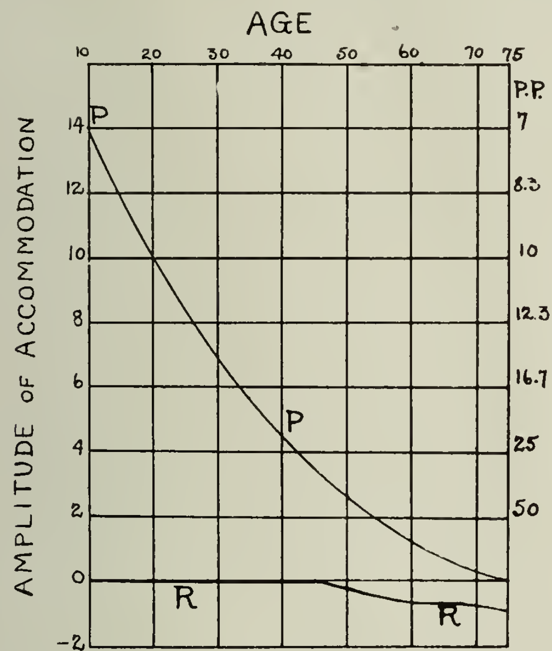


Fig. 45.—Static and Dynamic Refraction in the Emmetropic Eye. (After Donders.)

to the static myopia. The curve will then follow parallel to the line *RR* for emmetropia in everywise; the myopic *RR* curve may not, however, if the myopia is sufficiently great, ever cross over into the negative portion of the diagram. A myope of 1 D. will become emmetropic for distance at approximately 65 to 70 years according to these curves. In the case of hyperopia the entire curve *RR* will be below the zero line since hyperopia may be optically regarded as a deficit of refractive power. The decrease in refraction which is due to advancing age is added to the original hyperopia and increases it.

Likewise, as a general proposition, the change in the amplitude of accommodation is the same whatever be the refractive condition of

the eye. Emmetropia and ametropia are alike subject to these laws governing the range of accommodative amplitude at different periods of life. If then the amplitudes of accommodation are practically independent of ametropic condition, for ametropia one has only to displace the zero line or the *RR* line to the condition of static refraction found and to bear in mind the ordinates in order to obtain the values along the *PP* curve. For example, assume a myopia of 6 D.; the curve *RR* would therefore have its zero point changed to + 6 and it would terminate on the right of the diagram (Fig. 45) between + 4 and + 3 D.; the curve *PP* would commence at 14 + 6 = 20 divisions above the zero line and would descend as in emmetropia. But while the range of accommodation (amplitude) is equal for different conditions of the static refraction of an eye, the positions of the near and far points are evidently not the same.

74. If the proportion of the total accommodation that can be comfortably and economically exerted be taken as one-half, then the *presbyopic correction*, D_P, in diopters can be found from the expression

$$D_P = D_R - \frac{A}{2}$$

in which D_R represents the dioptric value of the desired reading distance and A the amplitude of accommodation *supposedly* possessed at a given age. The amplitude of accommodation in presbyopia can be found by adding arbitrarily sufficient convex lens power as to permit of the patient's reading normal type. A determination of the far and near reading points will give a fairly accurate estimation of the range of reading amplitude in presbyopic cases. To illustrate; a person over forty years of age is under observation; the static refraction having been determined and supplied it is found that he cannot read No. 2 or No. 3 Jaeger type (V = 0.50 D. to 0.62 D.) at the normal reading distance. A + 1 D. lens is supplied with which he can read all near test-types; the nearest point at which he can read No. 1 or No. 2 Jaeger type is 10 inches = 4 D. and the farthest is 20 inches = 2 D. The range of amplitude of accommodation as determined from the near and far reading points is, then, 2 D. According to Donders' table he should be about 50 years of age. If this person reads and does close work at 16 inches or 40 cms. there will be demanded an accommodative equivalent of 2.5 D. Being provided with a + 1 D. S. and possessing 2 D. of amplitude, his accommodative resources will be sufficient theoretically, but practically they will not be, in general,

since at least a good third of the total accommodation should be kept in reserve. Hence, approximately a $+ 1.50$ D. S. or $+ 1.75$ D. S. should be supplied.

When presbyopia is corrected the eyes are rendered artificially myopic by the convex lenses given and the range of accommodation is limited as in myopia. Suppose an emmetrope, or an ametrope made emmetropic by lenses, has 2 D. amplitude of accommodation; his punctum remotum is at infinity and his punctum proximum is at 50 cms. In order to correct the presbyopia present suppose $+ 1.5$ D. lenses be given for 40 cms.; then the range of vision is between the artificial far point which is at $\dfrac{100}{1.5} = 66$ cms. and the punctum proximum which is at $\dfrac{100}{2 + 1.5} = 28$ cms. With the presbyopic correction given for 40 cms. he can see as far away as 66 cms. by a relaxation of all accommodative effort and as near as 28 cms. by exerting all his accommodation. Expressed in diopters, the far point is represented by the correcting convex lens and the near point by the convex lens plus the accommodative amplitude; in this case, then, $A = P - R = 3.5 - 1.5$ D. $= 2$ D. When the amplitude is greatly depleted the range of accommodation with the reading (or presbyopic) correction is very restricted. When the presbyopia is incipient the range is fairly large but becomes smaller as the natural accommodation is replaced by the artificial accommodation of convex lenses until, when it is all artificial, the amplitude becomes zero, the near and far reading points coincide and the presbyope can see clearly at one distance only with his correcting lenses.

75. *Aphakia.* Aphakia is due to absence of the crystalline lens and is a refractive anomaly of the eye usually due to artificial causes, i. e., extraction of the lens on account of cataract or dislocation of the crystalline from traumatism, but it is rarely congenital. When the crystalline lens, which has a power of about 16 D. *in situ,* is removed there is produced in an originally emmetropic eye a high degree of hyperopia. This defect can be corrected by a convex lens of less than $+ 16$ D. power however. Accommodative action is nil; a few cases are on record where a patient has apparently been able to see distance and read ordinary type with the same lens, but in these cases the pupils invariably resembled narrow slits; with such a pupil and looking

obliquely downward through a strong convex lens it would be possible to read fairly small type since the peripheral portions of a high convex lens are more powerful dioptrically than the central portions, hence affording added lenticular assistance in reading.

When the crystalline lens is extracted the eye is reduced to an optical system of one refracting medium, the cornea, which then forms with the aqueous and vitreous a uniform medium of index approximating 1.33. If the length of the reduced eye be taken as 24 mms. and the radius of the cornea as 8 mms., then the anterior focal length, F_1, of the cornea is 24 mms. and the posterior focal length, F_2, is 32 mms. Hence the image in such an eye, devoid of the crystalline lens or its equivalent refractive power, tends to be formed considerably back of the retina and a clear retinal image can only be obtained by the use of a high power convex lens. This retinal image will, likewise, be considerably enlarged. The formula for conjugate foci of a single refracting surface is

$$\frac{F_1}{f_1} + \frac{F_2}{f_2} = 1$$

In this case $F_1 = 24$ mms., $F_2 = 32$ mms. and $f_2 =$ the length of the eye globe $= 24$ mms. By substitution we have $f_1 = -72$ mms. The eye has, therefore, a far point equal to 72 mms. behind the cornea or $^{1000}/_{72} = 14$ D. of hyperopia. If the correcting lens is put 15 mms. in front of the cornea, the focal length of the correcting lens should be $72 + 15$ mms. $= 87$ mms. which represents a dioptral power of 11.5 D.

It would be incorrect to apply this numerical solution to all aphakic conditions; the original ametropic condition must be considered. The mathematical expression which we have just used is, however, applicable to the calculation of f_1 under any condition of length of globe, f_2. The lens correcting an aphakic eye in which the previously existing ametropia was known can be calculated in the same manner as for emmetropia. For example, suppose a myopia of 6 diopters existent before operation. Axially this eye is 2 mms. longer than the normal eye; hence $f_2 = 26$ mms. and $F_1 = 24$ mms. and $F_2 = 32$ mms. as before. Therefore, $\frac{F_1}{f_1} + \frac{F_2}{f_2} = 1$ gives $f_1 = -104$ mms (behind the cornea); the correcting lens, being placed at 15 mms. in front of the cornea, must have a focal length of $104 + 15$ mms. or practically a

dioptric power of + 8 D. An operation involving the cornea affects its general refracting power as well as causing astigmatism. Also, if the normal eye is 25 mms. in length and the corneal radius is 7.5 mms., the correcting lens in aphakia for an eye originally emmetropic would be weaker than 11.5 D.; calculation gives about 10 D. The following table was calculated by Dr. Stadfeldt.

Before operation	H = 7 D.	H = 5	H = 3	H = 1	E (= 0)
After operation	H = 15 D.	H = 13.8	H = 12.5	H = 11.3	H = 10.6
	M = 1	M = 3	M = 5	M = 7	M = 9
	H = 10.1	H = 8.9	H = 7.8	H = 6.6	H = 5.5
	M = 11	M = 13	M = 15	M = 17	M = 19
	H = 4.4	H = 3.4	H = 2.3	H = 1.3	H = 0.2
	M = 21	M = 23	M = 25		
	M = 0.8	M = 1.8	M = 2.7		

Pflueger, in his published results on a series of measurements before and after operation, concludes that the above values are approximately correct. His results show:—

Before operation—

M = 10 D.	M = 11	M = 12	M = 14	M = 16	M = 18	M = 22

After operation—

H = 5 D.	H = 5.5	H = 3.5	H = 3.5	H = 2.5	M = 2	M = 2

In order that an eye may be emmetropic after extraction of the crystalline it must previously have been myopic about 18 diopters. An approximate calculation as to the correcting lens is to add half the original correcting lens to 11 D. for the aphakic correction.

76. One or two points of optical procedure are worthy of note. The usual correction for aphakia following operation is a sphero-cylinder. These corrections are made up, in common usage, as a sphere on one side and a cylinder on the side nearest to the eye. This virtually amounts to a lens of plano-convex form while trial case lenses are double convex. The optical centers and principal planes being differently situated the sphero-cylindrical correction may not be quite equivalent to the trial case findings. Of greater importance, however, is the accurate record of the distance of the trial case lenses from the cornea; several instruments, such as the Wessely keratometer (Bausch & Lomb), are on the market by means of which such measurements may be made. The subjective findings in the trial frame can thus be reduced to their equivalent vertex refraction and the proper correction produced for any distance of the lens from the eye provided the

original distances of the trial lenses are known. The influence of the distance from the cornea upon the power of a sphero-cylindrical lens ocularly considered is considerable. An eye is corrected, for example, by a + 10 D. S. ⊃ + 4 cyl. at 15 mms. from the cornea. The lens has a focal length of 100 mms. in one meridian and 71 mms. in the other. The far point of the eye in one meridian is, therefore, 100 — 15 mms. = 85 mms., corresponding to a dioptric value of 11.75 D., and in the other meridian a far point of 71 — 15 = 56 mms. or 17.9 D. The astigmatism is really then 6 D. (approximately) instead of 4 D. This calculation elicits the statement that the ophthalmometric determinations give, with slight error, the true astigmatism of the eye considered as residing in the anterior corneal surface. In a case such as that just described, assuming that the astigmatism is not too irregular to be suitable for measurement with an ophthalmometer, the ophthalmometric reading would be higher than subjective tests would indicate. In the case of simple cylinders the same statement holds; a subjectively found convex cylinder of 6 D. corresponds to a true astigmatic error of about 6.5 D.; a concave cylinder of 6 D., on the other hand, with one of 5.5 D. Again, suppose the correction + 10 D. S. ⊃ + 4 cyl. was found at 15 mms. Suppose this is optically ground and furnished the patient so that it stands 12 mms. from the cornea. Our calculations then give 100 — 12 mms. = 88 mms. or 11.4 D. and in the other meridian 71 — 12 mms. = 59 mms. or 16.9 D. and the astigmatic difference is 5.5 D. The original correction showed a real astigmatism of 6 D.; hence this same correction worn at 12 mms. instead of 15 mms. would under-correct the astigmatism by 0.5 D. These are important practical points.

VII. CIRCLES OF DIFFUSION

77. When the image of a distant point object is received upon a screen and this, in turn, is moved to and fro, one position will be found in which the image is most distinct. In other positions of the screen there will be found a luminous spot of the same shape as that of the aperture in front of the lens and which changes its size and its brightness as the screen is advanced. This luminous spot is known as the *circle of diffusion*. The same phenomena occur in any lens system and the eye is no exception. But inasmuch as the retina is fixed in position the luminous object point must be moved. The pupil, being normally circular, will cause a round image of diffusion. If an object of finite size is employed and the image is formed in front of or behind the retina, then each point of the object produces on the retina a circle of diffusion which is overlapped by the next circle, except near

the edges of the diffuse image in toto. Around the contour of the object there is also formed a border which is equal to half the diameter of the circle of diffusion and the intensity of which diminishes toward the periphery. The size of the circle of diffusion can be calculated from the relation

$$r = \frac{pd}{d + f} \qquad \text{(I)}$$

in which *p* represents the diameter of the pupil of exit, *f* its distance from the retina and *d* the distance of the distinct image from the retina, while *r* represents the diameter of the circle of diffusion. Of course the quantity *d* may be an additive or subtractive term in the denominator of the above fraction depending upon the refractive

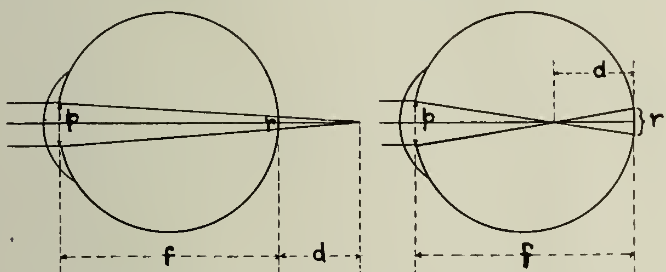


Fig. 46.—Size of the Circles of Diffusion.

anomaly. For hyperopia $r = \frac{pd}{d + f}$ and for myopia $r = \frac{pd}{d - f}$.

Fig. 46 illustrates the hyperopic and myopic conditions. The above relations can be deduced from it by the similarity of triangles. These effects have important bearing upon the size and clearness of retinal images under different ametropic conditions: the "blurriness" in astigmatism is explained by the overlapping or diffusion circles. If the pupil becomes smaller the diffusion circles are decreased. Contraction of the pupil, through the sphincter, is the normal accompaniment of accommodation: it is probable that the relatively high visual acuity of hyperopes may be accounted for in part by the reduction in the size of the diffusion circles through pupillary contraction. Especially is this true at the punctum proximum. The pupillary diameter decreases in general with age; this, according to Sulzer, explains why the belief has arisen that myopia decreases with age. The experiments of Bertrand have shown that in emmetropia a 3 mm.

pupillary diameter gives the best visual acuity; for 0.5 D. myopia a pupil of 2.5 mm.; 1 D. myopia, 1.75 mm.; 2 D. myopia, 1 mm.; 9 D. myopia, 0.5 mm. One, therefore, readily comprehends why ametropes and presbyopes prefer strong or powerful illumination since, by a contraction of the pupil under such influences, there is produced a considerable improvement in visual acuity. For a myopia of 2 D. with a pupil of 4.5 mms. a letter of 45 mms. size can be read at a distance of 5 meters; with a pupil of 1 mm. such a myope can read a small letter of 6 mms., that is to say, about 8 times smaller than the first sized letter, placed at the same distance. According to Bertrand a myope of 4 D., whose pupillary diameter can be reduced to 1 mm., will have the effects of his ametropic condition neutralized. The influence of the pupillary diameter upon the size of the circles of diffusion explains, in part, the great differences in the visual acuity of ametropes of the same degree.

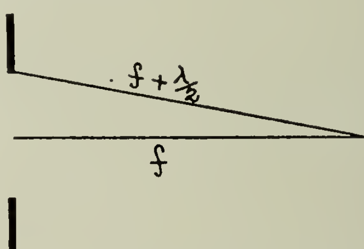


Fig. 47.—Illustrative of the Condition of Improvement of Vision by Small Apertures.

78. The improvement of vision produced by looking through an opening smaller than the pupil, as for example a pin-hole or a *stenopaic slit,* is due to the diminution of the circles of diffusion. This is why myopes see better at a distance and why in a great many instances vision is considerably improved by the subject due to the formation of a natural slit by narrowing the palpebral fissure; this is particularly true in myopic astigmatism. Such an opening can also be used as a magnifying device; an object can be moved very close to the eye and a large retinal image thus obtained; there is, of course, a loss of image brightness at the same time since the same total luminosity is distributed over a larger retinal area. There is a limit to the smallness of the size of the stenopaic opening, however. It is a theorem of physical optics that the maximum concentration of light at the center of an image is obtained when the axial and marginal rays coming through the hole differ in length by one-half a wave-length of the light employed. This is illustrated in Fig. 47, where the ray coming

from the edge of the hole is represented as $\frac{\lambda}{2}$ longer than the central ray *f,* λ being the wave-length of the incident light. If *r* is the radius of the hole, then it follows that

$$r^2 = \left(f + \frac{\lambda}{2}\right)^2 - f^2$$
$$= \lambda \cdot f \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (II)$$

when $\frac{\lambda^2}{4}$ is negligible. Hence the limiting value physically is given by $r = \sqrt{\lambda \cdot f}$. If a luminous point which is distinctly seen is looked at through a very small opening it will become enlarged into a small luminous surface surrounded with bright rings. The effect of *diffraction,* according to Tscherning, begins to play a part with an aperture of the pupil or of the stenopaic opening of about 2 millimeters. This explains why very small apertures should be avoided in retinoscopes used for skiascopic investigations of refractive errors. A too strong illumination should also be shunned since pupillary contractions thereby result which are not present when the patient is under normal and work-a-day conditions. Likewise these statements should serve as a warning against the use of too narrow stenopaic openings in the determination of refractive errors. In passing it may be stated that such openings improve the visual acuity not only because of a reduction of diffusion circles but also because they eliminate spherical aberration effects, a subject yet to be discussed.

79. The diffraction caused by a circular screen of radius *p* gives rise to concentric dark rings. The first minimum, as proven by Neumann, occurs when the angle of diffraction is such that

$$\sin \Phi = 0.61 \frac{\lambda}{p} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (III)$$

From equation II, $r = \sqrt{\lambda \cdot f}$ or δ, the diameter, equals $2\sqrt{\lambda \cdot f}$. Since the arc divided by the angle in radians is always equal to the radius, then, from equation III,

$$\delta = \frac{\lambda}{\Phi} = \frac{p}{0.61} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (IV)$$

since $\delta^2 = 4\lambda \cdot f$, then $\delta \cdot \delta = 4\lambda \cdot f$ and a substitution of the value of δ just deduced gives the equation

$$\delta = 2.440 \frac{\lambda \cdot f}{p}$$

If, then, p is the diameter of the aperture of the refracting system, f the position of the image produced by the same, λ the wave-length of light, the diameter of the mean diffusion circle, δ, is given by the expression

$$\delta = 2.440 \frac{\lambda \cdot f}{p} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(V)}.$$

Taking λ as $\frac{1}{2000}$ mm. as the average wave-length and f of the eye equal to 20 mms., expression (V) reduces to

$$\delta = 0.0244 \frac{1}{p}.$$

If, then, the smallest pupillary diameter is taken as 2 mms., $\delta = 0.0122$ mm. This size of the diffusion circle corresponds to a visual angle

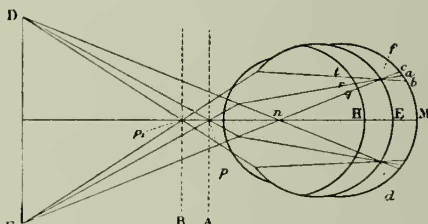


Fig. 48.—Effect of a Stenopaic Opening.

of 2 minutes and 6 seconds. Since the minimum visual angle separating two points is usually taken as 1 minute, it can be readily seen that the diffraction produced by very narrow pupils must influence the acuteness of vision.

The effects of a narrow stenopaic opening upon the size of retinal images in various refractive conditions can be seen from an inspection of Fig. 48. Let DF be a line object and df its retinal image which we construct by tracing the straight lines passing through the nodal point n. H indicates the position of the retina in an hyperopic eye, E of an emmetropic and M of a myopic eye. Place in front of the

eye a screen *A*, perforated at the point *P*, situated on the axis. The only rays proceeding from F which can, under these conditions, enter the eye is the ray *FP*, with the result that, in the hyperopic eye, the image is not formed at *q* but at *r*. The image of *DF* is then correspondingly enlarged and it will be found that the magnifying effects will be increased if the screen *A* is moved farther from the eye. In the myopic eye the image is not formed at *a* but rather at *b*, with the slit at *A*, with the result that the retinal images are minimized.

VIII. CHROMATIC ABERRATION

80. A point source of white light on the axis of a single lens never gives rise to an image at a single point. There are two effects which vitiate this much to be desired result, namely, *chromatic* and *spherical aberrations*. The latter of these defects finds its counterpart in the eye and has to do with distortion, unequal magnification and curvatures of the image. Chromatic aberration of a lens arises from the consideration that every lens is fundamentally a composite prism and every prism has an angle of refraction, an angle of deviation, a resolving power and a dispersive power. This last property is its ability to produce from composite light a spectrum or analysis of its constituent parts. A lens, therefore, if one considers the central portion only, causes a series of colored images or points to be formed on the axis, the blue end of the spectrum being nearer the lens. This is represented in Fig. 49. If a single lens is used to form an image on a screen it will be impossible for the various colored images to be simultaneously in focus. The ordinary lens formula is

$$\frac{1}{F} = (n-1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

wherein *F* and *n* represent the average focus and index respectively for yellow (D line) light. Writing the above equation, in turn, for F_r and F_b, where *r* represents red (C line) and *b* blue (G line), we have by subtraction

$$\frac{1}{F_b} - \frac{1}{F_r} = \frac{n_b - n_r}{n-1} \cdot \frac{1}{F}$$

$$\text{or} \quad F_r - F_b = \frac{n_b - n_r}{n-1} \cdot F.$$

Hence the chromatic aberration for parallel rays is equal to the mean

focal length of the lens multiplied by the dispersive power of the substance of which the lens is composed. *Achromatism* may be obtained under certain conditions with two or more lenses; if the lenses are in contact achromatism exists when

$$\frac{\omega_1}{F_1} + \frac{\omega_2}{F_2} = 0,$$

an equation which states that the dispersive powers (ω_1 and ω_2) are inversely proportional to the focal lengths. This equation also shows that one lens of the combination is, of necessity, a concave or minus dioptric power member when the two lenses making up the combination are in contact.

81. The eye is not an achromatic combination although, in everyday life, the chromatic aberration is not noticeable. That it does possess this error can be shown by the following simple experiment: look through a pinhole at the line of separation of a roof against a bright sky. Slowly raise the pinhole, which will allow light to enter the peripheral portions of the pupillary area. The sky just above the roof will appear of a reddish color. A flame, when thus looked at, will appear blue in the upper portion and red in the lower part. This is explicable remembering that retinal images are inverted and that light when incident at the upper edges of the lens will have its blue component deviated downward more than its red component. A ready experimental test is to color a printed page in alternate red and blue indigo or cobalt blue and attempt to read; the constant change of focus demanded is small but extremely annoying. Another method of rendering the chromatic phenomena of the eye easily visible consists in eliminating the middle of the pupil by means of a narrow ribbon of black paper. A white line on a black background, placed inside of the far point, will then appear double; the inner borders of the two lines will appear blue and the outside edges red. If the object is placed outside of the punctum remotum these phenomena will be reversed; also, if the colors of object and background are interchanged the order of colors will be reversed. Or if one half of the pupil be occluded by a card, the eye is converted into a strong prismo-sphere and the colored fringes will fall upon the macula and be seen as such when a small white body on a black background is viewed. If the lower half of the pupil be covered the exposed half of the eye acts as a prism base down so that a blue-violet fringe is seen at the upper and a red-orange fringe at the lower edge of a luminous body.

We frequently observe very striking phenomena due to ocular chromatic aberration by fixing black objects on a white ground placed at a distance for which the eye cannot accommodate itself. When looked at toward the sky, the slits of the optometer of Young present very vivid colorings.

The chromatic aberration increases with the diameter of the pupil. It is useful, therefore, in studying it to make use of mydriatics.

82. Young made the first estimates upon the chromatic aberration of the eye, while Fraunhofer made the first reliable measurements on the difference in the focal lengths of the eye for the extreme spectral colors. He observed a prismatic spectrum through an achromatic telescope the eye-piece of which carried a cross-hair. Fraunhofer noticed that he had to move the ocular nearer the cross-hairs, for clear vision, when observing the violet portions in contradistinction to the

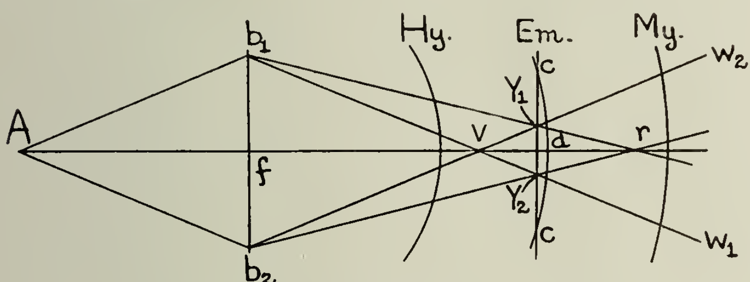


Fig. 49.—Chromatic Aberration of a Lens.

red regions. By fixing an external point with one eye he so adjusted the eye-piece as to give equal distinctness of the cross-hair and object in two spectral regions. The optical constants of the eye-piece being known, the corresponding visual distances could be found. He discovered from these researches that an eye which sees, without accommodation or practically at infinity, an object of color corresponding to the spectral line C (between orange and red) cannot see this object clearly, with the same accommodative status, in light of wave-length corresponding to line G (between green and blue) unless it is some 18 to 24 inches nearer the eye. Helmholtz modified the experiment somewhat and allowed monochromatic light to pass through a very small opening in a screen; he then determined the greatest distance at which this opening still remained of pin-point form. The greatest visual distance in red light was 8 feet, in violet 1.5 feet and in the extreme violet bordering on the ultraviolet about 1 foot. These data show that Fraunhofer found about 1.5 to 3 D. and Helmholtz 1.8 D. as the chromatic aberration of the eye.

A luminous point seen through a prism gives a linear spectrum. If the experiment is made, however, the whole of the spectrum is not at one and the same time distinctly seen. If the luminous point is at a considerable distance, the emmetropic eye will see the red extremity of the spectrum as a distinct band or ribbon (line) while the blue extremity will be enlarged, fuzzy or diffuse. If the luminous source be approached, the eye still not accommodating, a distance will be found such that the blue end of the spectrum will be sharp and the red portion, in turn, indistinct. A determination of the far point for each end of the spectrum will give a measure of the degree of chromatic aberration.

83. The *cobalt glass test* has been and is still at times used in the determination of refractive conditions. It is based in operation upon the chromatic aberration of the eye. If a distant point light source is viewed through the glass, which transmits only the extreme portions of the spectrum, and the eye is emmetropic, one composite color effect only will be noticed. If the eye is hyperopic, the far point is back of the retina and the conditions shown at *Hy* in Fig. 49 will be present; that is to say, a blue center surrounded by a red halo. If, in turn, the myopic condition *My* (Fig. 49) is investigated just the reverse positions of the color phenomena will occur. If, then, the luminous object is inside the near point it will be seen as blue surrounded by a red halo; if the luminous point is beyond the far point there will be, on the contrary, a red center surrounded with blue.

84. Recently Nutting has given a precise method for determining the axial focal lengths. The monochromatic rays from a Nernst or mercury lamp pass through a slit and then through a moveable achromatic lens, of 20 cms. focal length, to the eye. The image of the slit formed by the lens serves as a test object. The accommodation is fixed by means of a glass plate placed at 45 degrees between the eye and the lens, reflecting the image of a side object, such as a dark letter or distant tree trunk, at the desired distance. A shift of the lens by 1 cm. corresponded, in Nutting's experimentation, to 0.01 mm. shift in focal point at the retina. The results of seven observers are shown in Fig. 50. The axial error curve for pure water is given for comparison. In the most luminous part of the spectrum, from $\lambda = 5200$ to $\lambda = 6600$ Angstroms, all eyes tested showed less variation in focus than an equivalent eye of pure water would have.

Since the refractive indices of the optical media of the eye do not differ greatly from the index of water, the above comparison of experimental results with the human eye to the "pure water" eye seems legitimate. The refractive indices for water for various wave lengths

may be taken as follows: for red light (line C) 1.331705, for violet light (line G) 1.341285. Applying the methods for calculating reduced eyes to the Listing eye, having the radius of its refracting surface equal to 5.125 mms. and using the above indices, the focal lengths can be calculated as 20.574 mms. for the red and 20.140 mms. for the blue. This gives a chromatic aberration of 0.434 mm. which corresponds to practically 1.1 D. Or, if an eye is accommodated for infinity for the red so that the retina is at the focal point of the red rays, then the focus for the blue rays lies some 0.434 mm. in front of it, with the result that this eye must accommodate for a 26-foot distance

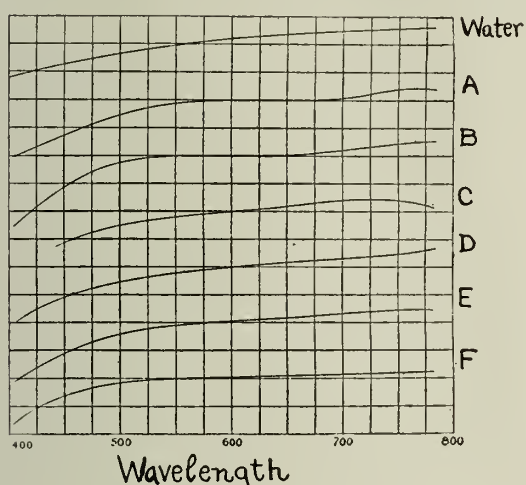


Fig. 50.—Curves of Nutting on the Axial Focal Lengths of the Eyes of Various Observers for Different Wave-lengths of Light.

in order to bring the blue in focus upon the retina. Fraunhofer found in his own eyes 18 to 24 feet. Helmholtz obtained similar results. Matthiessen calculated from his researches on this subject about 0.58 to 0.62 mm. instead of Nutting's value of 0.434 mm. The results obtained by different observers following various experimental methods indicate that the human eye approaches very closely in its chromatic aberration to an eye of distilled water but that it probably has a greater dispersion.

85. While the eye is not achromatic, yet when an object is at such a distance that it can be seen distinctly we do not see it surrounded with colored borders. An explanation can be given somewhat as follows:—Let A (Fig. 49) be a luminous object which sends the cone Ab_1b_2 into the eye. After refraction, chromatic aberration occurs;

the red rays form the cone b_1rb_2 and the violet rays the cone b_1vb_2 and the eye accommodates itself in such a way that the retina is between the two foci, placed so that the red and blue diffusion circles overlap at y_1y_2. The yellow and the green portions of the spectrum, which are intermediate between red and blue, and which are the most useful visually, are therefore concentrated at the middle of the diffusion circle when they coincide with a portion of the red and of the blue. The peripheral parts of the red and violet form a purple border all the way around but this border is very narrow, since the region y_1y_2 is specified and known as the *circle of least confusion.* Being formed by the extreme spectral rays, which are of little service visually, this border is too weak to be perceived. In order to calculate the size of this circle, y_1y_2, we need to consider the eye as a Listing's reduced eye of water. From Fig. 49 it follows that

$$\frac{y_1y_2}{b_1b_2} = \frac{dr}{fr} = \frac{dv}{fv}$$

$$\text{Therefore,}\quad y_1y_2 \cdot fr = b_1b_2 \cdot dr$$
$$\text{and}\quad y_1y_2 \cdot fv = b_1b_2 \cdot dv.$$

By addition there follows the equation

$$\begin{aligned} y_1y_2\,[fr + fv] &= b_1b_2\,[dr + dv] \\ &= b_1b_2\,[fr - fv] \end{aligned}$$

$$\text{Hence}\quad y_1y_2 = b_1b_2 \frac{fr - fv}{fr + fv}.$$

If b_1b_2 is placed equal to the average diameter of the normal pupil, i. e., 4 mms., and the determinations of the focal lengths of the reduced "water" eye used, in which $fr = 20.574$ mms. and $fv = 20.140$ mms., then $y_1y_2 = 0.0426$ mm. A calculation similar to that made by Helmholtz (*Physiologische Optik,* I Band, edition 1909, page 111) for the Listing's eye shows that the size of this dispersion circle is the same as that which is produced when a luminous point is situated at 1.5 meter from the eye adjusted for infinity. Such a variation in the accommodation should produce a decided inexactness of image. In order to explain why the chromatic dispersion in the eye produces no noticeable inequality of images in spite of the inequality of the circles of least confusion one must consider not only the size but also the distribution of light in these circles. This question of brightness

distribution Helmholtz has discussed in a masterly manner. His mathematical calculations lead to a curve of the shape shown in Fig. 51. The distances from the center are plotted along the horizontal or "x" line; the brightness along the vertical or "y" line. The line *ab* corresponds to the brightness of the middle of the surface; *c* corresponds to the position of its edge; the dotted line *adc* shows the brightness distribution of a very sharp, clear image. The limits of the dispersion circle from *c* are *b* and *g*. The curve shows clearly that the brightness curve falls off extremely rapidly at the point *f* and that the portion of the curve *fg* and area of luminosity *fgc* are fairly negligible.

Clearness or sharpness of vision is not apparently produced by the correction of chromatic aberration. An eye can be corrected for these errors by means of a concave lens of flint in the same manner as a convex lens of crown glass can be achromatized. The dispersive

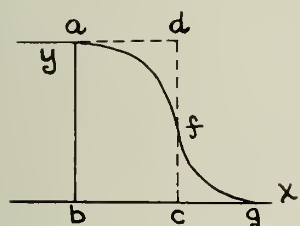


Fig. 51.—Illustrating Brightness Distribution. (After Helmholtz.)

power of glass is about one-third that of the eye; since the refracting power of the eye is approximately 60 diopters there would be needed a concave flint lens of about 20 D. A myope of 20 D., fitted with a flint glass lens, would have his ametropic and chromatic defects simultaneously corrected. An emmetrope would need in addition a second achromatic convex system in order to optically neutralize the concave lens correcting the chromatic aberration. This could be done by means of a lens of crown and flint components so calculated that their combined dioptric powers would be zero for yellow, about + 0.5 D. for red and — 1 D. for blue light. To accomplish this the crown glass component would need to be about + 66 D. of refractive efficiency (ν) equal to 55 and the flint component — 66 D. of refractive efficiency $\nu = 27.5$. Although the effects of chromatic aberration are quite negligible, an ordinary convex lens tends to increase and a concave lens to decrease the natural chromatism of the eye before which it is placed.

IX. SPHERICAL ABERRATION

86. *Caustic caused by refraction at a curved surface and the phenomenon of spherical aberration as exhibited by a lens.* In Fig. 52 let *AMP* be a spherical surface of which *C* is the center of curvature, *P* the pole and *PC*, produced, the axis. Air and glass are the media. The paths of the various refracted rays due to the incident parallel rays may be found according to the law of refraction. It will be seen that the rays refracted near the pole cut the axis and each other at a point *F*. On the other hand, rays refracted at the surface remote from the pole cut the axis at points nearer to the surface than *F*. The more remote the point of incidence the nearer the point at which the refracted rays cut the axis. This phenomenon is termed *spherical aberration*. Rays refracted at neighboring points of the surface somewhat remote from *P* intersect each other before reaching the axis.

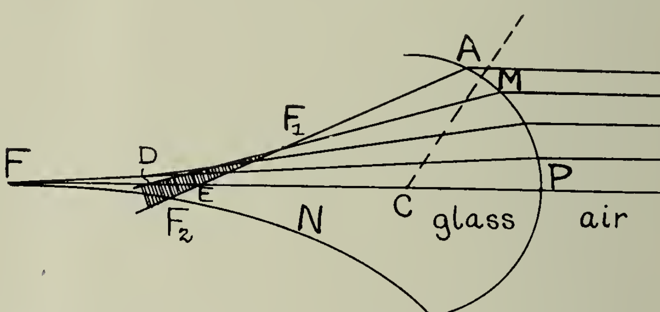


Fig. 52.—Focal Lines Formed by Refraction at a Spherical Surface.

Each point of intersection is a sort of focal point; the curve joining them is termed the *caustic curve;* its form is indicated in the lower portion of the diagram as *FN*. Taking any two isolated rays at *A* and *M* remote from the axis, together with the corresponding refracted rays *AE* and *MD*, we see that these rays cut each other at F_1. Supposing everything rotated through a small angle to give a surface instead of a cross-sectional view, it will be found that a parallel pencil incident at *AM* gives rise to an astigmatic pencil passing through two perpendicular lines at F_1 and F_2 respectively. These lines at F_1 and F_2 are known as the *first* and *second focal lines.* Somewhere between F_1 and F_2 the section of the refracted pencil is approximately circular and is known as the *circle of least confusion.* It can be seen, then, that when the aperture is not very small the rays do not, after refraction, meet at a point; the peripheral portions are more refracting than the central ones. The degree of aberration increases as the square of

the aperture of the lens and as the cube of its refracting power. It likewise depends upon the distance of the object and the form of the lens. A lens, for example, having a central power of 20 D., when examined at a point 15 mms. from the lenticular center shows the following results:—crossed lens, 21.1 D.; plano-convex with the convex surface in front, 22.3 D.; bi-convex, 23.6 D. and plano-convex, with the plane surface toward the incident light, 23.8 D.

87. Schicner used a two-apertured opaque screen in his classic method of determining the near point and refractive condition of the

Fig. 53.—The Spherical Aberration of a Lens.

eye. This same device can be used to determine the aberration values and forms of image due to a lens. Four apertures may be used. These are equidistant; two are near the center and two are situated at the peripheral regions of the lens. The lens is illuminated with a broad light source at a considerable distance from it; a screen is used to receive the images and is placed in various positions with respect to the lens. Four images will be formed as shown in Fig. 53; if the screen is outside the principal focus for the central apertures the images will be inverted (A, Fig. 53); the central images will be circular and the peripheral images, in turn, spots elongated in the vertical direction due to eccentric refraction. By moving the screen nearer

(B), the two central images may be made to coincide; this gives the principal focal point of the near-central portion of the lens. Advancing the screen still nearer to the lens a position (E) will be found in which the peripheral region images will blend, hence giving the focal point due to the border portions of the lens. Passing on still nearer to the lens, the four images appear as shown in (G); they are now received on the screen, however, in such positions as put them in juxtaposition with the apertures which give rise to them. The peripheral spots are now elongated in the horizontal direction, however. To determine the degree of aberration it is necessary to measure the position of the focus of the central portions and again of the peripheral portions and take the difference between these distances expressed in diopters. If the circles of diffusion are to be examined no perforated screen is to be employed; as long as the screen is situated beyond the focus the light is concentrated at the middle of the circle and the brightness diminishes rapidly at the periphery; the distribu-

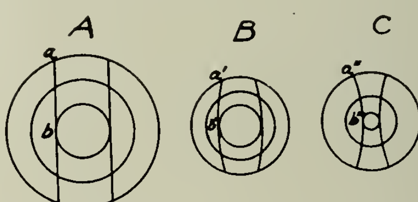


Fig. 54.—Deformation of the Shadows of a Needle by a Lens.

tion of luminosity is similar to that shown in Fig. 51. When the screen is inside the focus, however, there will be found a luminons disc surrounded by a more brilliant circle.

88. Images will be distorted or deformed because of spherical aberration. Likewise, shadows produced by placing an object, such as a needle, against the snrface of a lens, will exhibit similar effects upon a screen; the shadows are visible in the circle of diffnsion. These effects are illnstrated in Fig. 54. The shadow is straight only when the needle coincides with a diameter of the lens, otherwise it is curved. In Fig. 54, A, is shown the needle in contact with the lens. If the screen is between the focus and the lens the shadow will be concave toward the center (Fig. 54, B) and when placed outside the focus it will be convex toward the center (C). These results are explicable by reference to Fig. 53, which shows that after refraction the corresponding zones of the circle of diffusion diminish in width toward the periphery when the screen is situated between the focus and the lens, while they increase in turn toward the periphery beyond the

focal point. The concentric circles shown in Fig. 54 represent these corresponding zones; two needles are shown and represented by the heavy and dotted lines in order to indicate the direction of the curvature of the shadow and the position relative to the object which gives rise to it. An over-corrected lens exhibits all these phenomena but in the reverse order; an aplanatic lens is free from all of them and the shadow of the needle will remain straight in all positions of the screen.

89. *The aberration of the human eye. Young's researches.* The great savant, Young, prepared a series of experiments which conclusively prove that the eye is not aplanatic. (1) A myopic eye, or one which is mechanically made so by the addition of convex lens power, sees a distant luminous point as a circle of diffusion with its bright-

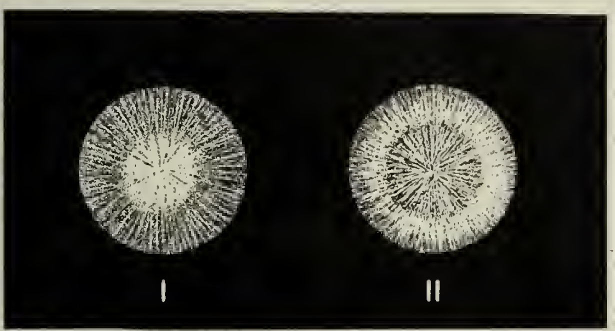


Fig. 55.—Distribution of the Light of the Circle of Diffusion in an Eye with Strong Aberration. (After Antonelli.)
In I the luminous point is beyond and in II within the focus.

ness concentrated at its center if the eye has positive spherical aberration. If the aberration is over-corrected, or if the luminous point is inside the far point, the peripheral regions will be the more luminous: an eye exhibiting such a condition is spoken of as possessing negative spherical aberration. These two conditions of under- and over-corrected or positive and negative aberrations may be seen objectively very often when an eye is examined by the methods peculiar to skiascopy, especially if the pupil is naturally or artificially dilated. The distribution of light in the circle of diffusion of an eye possessing strong aberration is shown in Fig. 55; in (I), with + 4.5 D. S., and exhibiting positive spherical aberration and in (II), with — 7 D. S. showing that the aberration is overcorrected. (2) Placing a needle in front of the eye made myopic during the performance of the test given in (1), the shadow of the needle will be seen in the circle of

diffusion. If the shadows remain straight at all points there is then no appreciable or perceptible aberration; if it is concave toward the periphery ordinary aberration is indicated but if it is concave toward the center there is evidence of an overcorrected aberration. If an eye is made hyperopic by means of a strong concave lens the observed phenomena are just the reverse of those given above if the accommodation is not exerted. This experiment can be performed with the needle in different meridians and proof obtained of the fact that the aberration is not always the same in the different directions.

90. *Experiments of Volkmann.* Volkmann applied the method of Scheiner, described in connection with Fig. 53, to determine the aberration of the eye. He used four openings in the positions indicated in Fig. 56 (A). Looking at a pin placed beyond the punctum remotum through these openings, four pins are seen as in Fig. 56 (B) *a*.

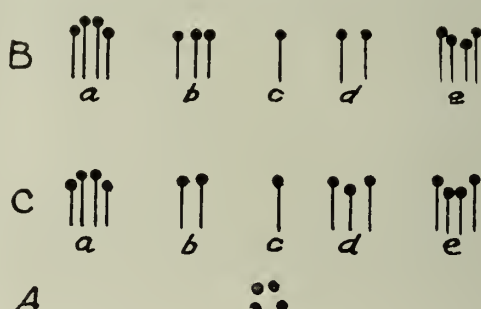


Fig. 56.—Illustrative of the Experiment of Volkmann.

By moving closer to the pin he observed the series of changes diagrammed in (B) in the order shown from *a* to *e;* these results are accounted for when they are compared with those shown in Fig. 53 illustrating the various images obtained by a lens exhibiting spherical aberration. In the position *b* the point is exactly at the far point of the central portions of the pupil since the two central images are united into one. It is still, however, beyond the focus of the peripheral portions since two peripheral images appear. In (C) are shown the observed order, number and relative positions of the images of the pin as seen by an eye over-corrected aberrationally. In the position *d*, Fig. 56 (C), the pin is at the far point of the central portions and within the peripheral far point. Tscherning remarks that it is probable that these latter results are due to accommodation because it is rare to find overcorrected aberration in an eye in a state of repose.

During accommodation the aberration is, as a general rule, overcorrected. This effect may be shown in a very simple manner as

described by Edser. Look with one eye, the other being occluded, at the upper edge of a printed square (or a sheet of paper) placed just beyond the shortest distance of distinct vision. Cover the eye slowly from below by means of a cover-card; just before the edge of the object viewed vanishes it will be seen to sink. The upper edge of the figure or sheet of paper lies on the optic axis of the eye. The rays from it, traversing the middle of the pupil, form an image at the point where the optic axis meets the retina. Those traversing the upper edge of the pupil are insufficiently deviated and thus form an image above the true one; the interpretation of objects in space by the law of projection causes the object viewed to appear to sink.

91. *The optometer of Thomas Young.* The optometer of Thomas Young,—of which Tscherning says: "It appears to me to be one of

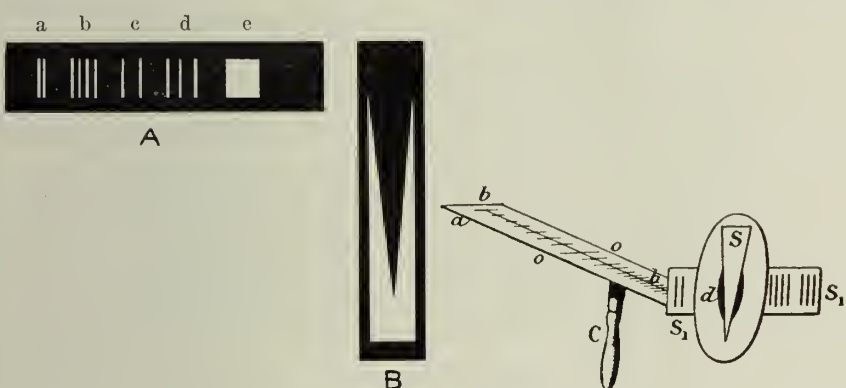


Fig. 57.—The Rules of the Optometer of Young.

the most important instruments for the study of physiologic optics,"—enables us to measure spherical aberration directly. It is in the form of a little rule carrying a fine white line on a black background on one side. The observer looks along this line through a + 10 D. lens. In front of the lens is placed a small horizontal rule, free to move and carrying different groups of slits. Two slits in this rule will act like the openings in the experiments of Scheiner. Each point of the line appears double except that which is seen distinctly; in this manner it may be used to determine the far point of an eye by placing a small cursor at the point where the observer sees the lines intersect. The rule carries various sets of slits differing in number and position thereby permitting the determination of the refraction at different parts of the pupillary space. One may also make use of a second form of rule,—placed vertical and having an M-opening thus producing a pointed metal triangle at the center of this M-shaped opening,—

to eliminate a greater or smaller portion of the middle of the pupil. These two instruments are shown in Fig. 57. The horizontal slide carrying the slits is as A and the vertical slide with the M-opening as B. The portions which are cut away or are open in these instruments are printed in white in Fig. 57.

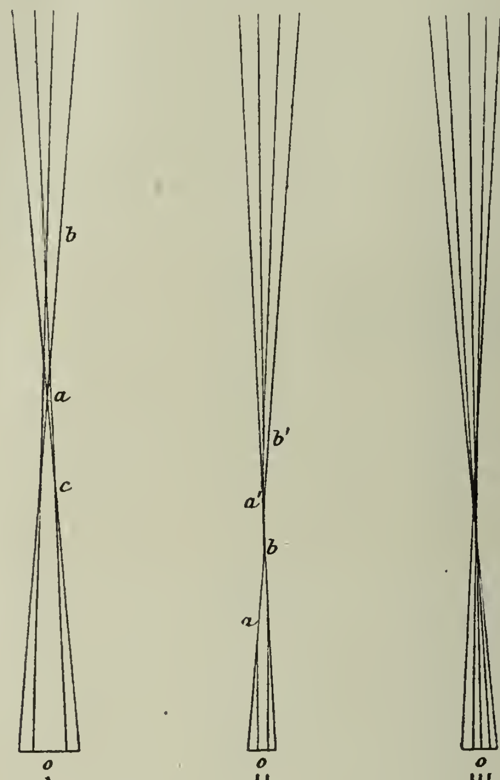
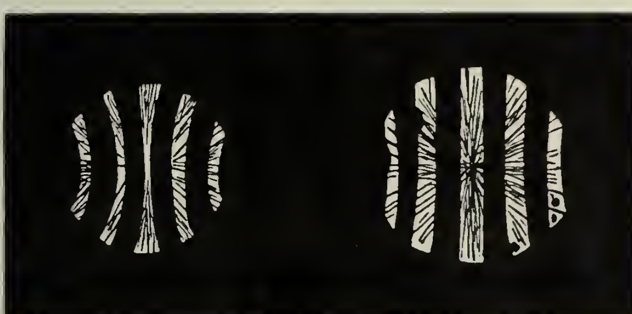


Fig. 58.—The Appearance of the Line of the Optometer of Young.

Seen through four slits by one eye with strong spherical aberration. O, position of the eye; a (a') far point of the peripheral parts; b (b') far point of the central parts.

This instrument does not afford a satisfactory device for the examination of refractive errors because it is extremely difficult for an inexperienced observer to use it without bringing into play his accommodation. If one can control his accommodation this instrument gives a means of measuring simultaneously both the refraction and amplitude of accommodation since the near point may be determined in the same manner as that described for the far point. This device of

Young does permit, however, of a direct measurement of aberration. In the horizontal rule (Fig. 57 A) there are placed at *a* two narrow slits very close together. The central refraction of an eye may thereby be determined by finding the point of intersection of the two apparent lines present when the observer looks at the single line along the auxiliary rule. The two apparent lines must be equally distinct; when this is the case the slits are practically at the center of the pupil. The quadrangular opening *e* is then slipped in front of the lens and the slide *B* carrying the triangular shaped piece is slowly lowered, thus cutting off a greater and greater portion of the middle of the pupil. Two lines will then be seen which separate farther and farther until one of the lines disappears. The difference between the measurement made at this point and that obtained by the central refraction



I II

Fig. 59.—Deformity of the Shadows in an Eye with Strong Spherical Aberration. (After Antonelli.)

I, in a state of repose; II, during accommodation.

using the two narrow slits measures the maximum degree of aberration. Young made these two measurements at the same time by employing four slits as shown at *b* in Fig. 57 A. This method is much better but is more troublesome. With the four slits a corresponding number of lines will be seen as in Fig. 58. If there is spherical aberration the central lines will intersect at a point *b* farther away than the peripheral lines which meet at *a*.

92. *The aberroscope of Tscherning.* Tscherning constructed a simple instrument known as the aberroscope for the subjective determination of aberration. It consists of a plano-convex lens, suitably mounted on a handle, on the plano side of which is cut a mesh of small squares. A distant luminous point is viewed through this lens, situated some 10 to 24 centimeters from the eye, and the observations made upon the character of the lines seen, i. e., as to whether they are curved or not. Most persons show a certain degree of positive aberra-

tion which corresponds closely to the toric form of the optic part of the cornea. Fig. 59 (I) shows the deformity of the shadows in an eye with strong aberration and when in a state of repose; part II of this figure shows that this aberration is largely corrected during the act of accommodation. Fig. 60 indicates that the aberration is overcorrected toward the borders and Fig. 61 shows aberration overcorrected in the entire pupillary space.

93. *Method of Stadfeldt and Tscherning.* Stadfeldt and Tscherning applied the method, devised by Foucault to examine his telescopes, in order to determine the aberration of the dead crystalline lens. Foucault's method, which may be applied to the study of the aberrations of any lens system, is essentially as follows. A luminous point is

Fig. 60.—Aberration Overcorrected Toward the Borders.

Fig. 61.—Aberration Overcorrected Everywhere.

placed a little beyond the principal focus of the lens to be investigated. The image will, therefore, be found at a considerable distance from this lens; the observer places himself beyond this image so that his eye is in the luminous pencil on the axis of the lens. By slowly approaching the lens the eye will see as luminous those portions of the lens which send rays to it. If the lens is aplanatic all rays will meet at the focal point and the whole lens will appear luminous to an eye situated at the focus; at other positions only a small central portion will be luminous since the other rays do not enter the eye. If the lens has spherical aberration a series of phenomena will be seen which are explicable by means of the constructions given in Figs. 52 and 53. When sufficiently far from the lens a small central spot only will be visible which increases in diameter as the focus is approached when it obtains its maximum size; this is shown in Fig. 62 (a). Approach-

ing still nearer, a luminous ring becomes visible, separated from the central part by a narrow, dark zone as shown in Fig. 62 (b). As the lens is approached this ring dilates more and more and becomes farther removed from the central spot which, in turn, contracts in size thus causing the dark zone to become enlarged. On reaching a certain point the ring extends to the border of the lens and finally disappears as shown in Fig. 62 (e). These phenomena are intensified if observed through a narrow aperture in front of the eye. An examination of Fig. 53 in conjunction with the drawings of Fig. 62 shows clearly that if the eye, considered as having a pupil reduced to a point, should be placed at E (Fig. 53), rays 1 and 4 would enter and the borders of the lens would appear luminous, while rays 2 and 3 would pass outside the pupil, thus producing the dark zone. A small luminous area will, however, always appear at the center since the axial rays enter the eye. The dioptral difference between the place where the ring first appears and where it disappears will measure the

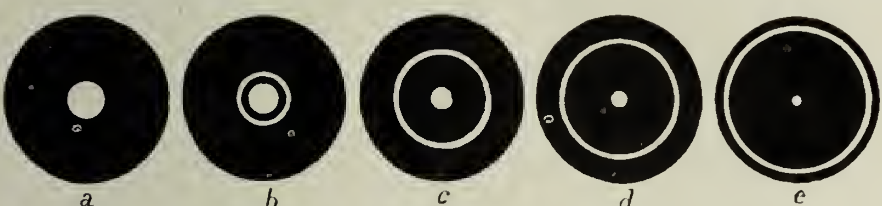


Fig. 62.—Phenomena of Spherical Aberration.

spherical aberration. Any lens system which is overcorrected will exhibit these phenomena in the reverse order and therefore the eye must be removed from, rather than approached toward, the lens in order to see the ring.

94. In order to study the aberration of the crystalline, Stadfeldt used the device shown in Fig. 63. The crystalline lens, removed from an eye in its capsule and with the zonula, was fixed in a ring which was, in turn, placed in a small receptacle filled with serum and enclosed front and back with glass plates and placed upon a stand, shown at A, moveable upon a graduated scale at ED. The lens C served to concentrate light upon a very small aperture in BD. The crystalline was observed by means of a telescope at K, and the diameter of the aberration ring, corresponding to a given distance between A and BD, determined by means of an ocular micrometer. After making the necessary reductions, the distance of the luminous point to the crystalline gives the focal distance of the zone which appears luminous. The series of changes diagrammed in Fig. 62 and discussed in connection

therewith occur in these investigations on the crystalline. When the condition shown in Fig. 62 (a) arises, i. e., when the aberration circle and the central luminous spot become one, the luminous point is at the principal focus for the central portion. The focus of the central portion can be obtained very accurately by removing the plate *BD* and substituting a microscope of low magnifying power in the tube *K*. An object placed at a considerable distance is first selected and the line of sight directed toward it; then, by displacing the carrier *A*, there is put in focus, first of all, the image of the distant object formed by the crystalline lens and then, in turn, the posterior surface of the lens itself. The difference between the two positions of *A* enables the

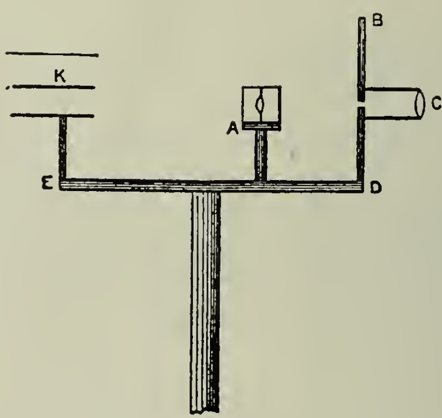


Fig. 63.—Instrument of Stadfeldt for Measuring the Aberration of the Crystalline Lens.

focal length of the lens to be calculated. Some of the various results obtained by Stadfeldt are given in the following table:

Distance from the central axis	Focal Lengths I	II	III	IV	V
0 mm	48.6 mms.	59.4	55.8	47.8	50.4
2	48.6	59.4	55.8	47.8	53.0
2.5	51.7	66.1	63.2	60.8	59.7
3	51.7	66.1	63.2	60.8	63.7
3.5	46.3	66.1	63.2	60.8	73.1
4	41	63.4	55.2	55.5	
4.3		56.8	47.2		

From these results we see that the central part of the crystalline lens of about 4 millimeters diameter (from 0 to 2 mm. in the above table) is very nearly aplanatic, that the aberration in the region comprised between 2 and 3 millimeters radius is overcorrected by an average of about 2 diopters and that the aberration from there on is undercorrected and falls off rapidly in the extreme peripheral regions. The decrease of the refraction in the paracentral zone must be attributed to a diminution in the index of refraction toward the periphery, while the increase of the refraction at the border must be due to the greater curvatures encountered there. The average central area refraction is 18 diopters, that of the paracentral zone 16 diopters anl that of the extreme peripheral portions, which play little part in general in vision, about 20 diopters.

95. In a general way spherical aberration increases with the angle of incidence. The anterior surface of the crystalline will produce little aberration since the rays incident upon it, as previously refracted by the cornea, will fall upon it nearly normally. The two surfaces chiefly instrumental in causing these errors are the cornea and the posterior surface of the lens, since the paths of the incident rays upon these surfaces are such as to make the angles most unfavorable. Tscherning has calculated the various aberrations for the three surfaces in a "large eye" and "small eye" as he terms them. The large eye has a radius of the cornea equal to 8.5 mms. and anterior and posterior lenticular surface radii of 12 mms. and 6 mms.; the corresponding quantities in the small eye are 7, 8 and 5 mms. respectively. The results as tabulated are:—

Diameter of Pupil (Apparent)	Large Eye 4mm.	6mm.	8mm.	Small Eye 4mm.	6mm.	8mm.
Aberration, cornea	1.0D	2.2D	4.6D	1.6D	4.1D	9.7D
Anterior crystalline	....	0.1	0.4	0.2	0.3	0.8
Posterior crystalline	1.0	2.5	5.5	1.9	5.0	11.7
Whole system	1.6	3.8	8.2	2.8	7.2	17.3

The aberration increases as the square of the aperture and inversely as the cube of the focal distance. It follows then that the spherical aberration will be more pronounced in eyes of small dimensions.

96. Exaggerated or large aberrational effects are found in keratoconus. The diagrams given in Fig. 64 are taken from the work of Cordiale. The abscissæ show the distances from the visual line in millimeters, while the ordinates give the aberration in diopters.

97. Although aberration may be quite pronounced it does not appear to injure the visual acuity much as long as it remains regular. The reason for this appears to be that the smallest diameter portion of the

cone is not used by patients. We know that at the focal point for the central rays, a luminous point has the form of a point surrounded by a feebly luminous halo. If the object observed has low luminous intensity this halo will be too weak to be seen and the image becomes good; if the luminosity is high the pupil excludes, by its contraction, the peripheral portions of the optical system in such a manner as to practically destroy the halo.

Aberration is a factor, however, which makes less accurate or impos-

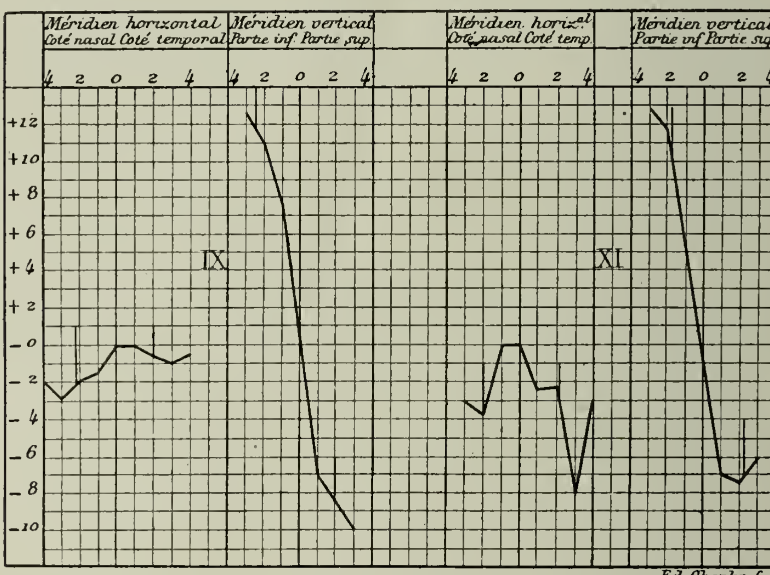


Fig. 64.—Curves Showing the Spherical Aberration in Two Cases of Keratoconus. (After Cordiale.)

The abscissæ indicate the distances in millimeters from the visual line; the ordinates the aberration in diopters.

sible the exact determination of the refractive condition of an eye especially if the aberration is not regular. We know that a section of the caustic (the most luminous part of the cone) has the form of an arrow and that it is the point of this arrow, formed at the focus by the rays centrally refracted, which in general serves for vision. As this is very pointed it follows that exact determination of the refraction cannot be made. The spherical aberration acts, in this respect, as a narrow diaphragm; it is difficult to determine accurately the focal length of a lens which is highly diaphragmed. Because of this form of caustic, eyes possessing a strong aberration can still have

visual acuity of the highest order. If the aberration is absent, that is to say if it is approximately corrected, it will serve as another source of uncertainty in the determination of the refraction. This is apparently paradoxical; it would appear that such an eye should be practically aplanatic. Such indeed it would be, but another factor enters into the question from the refractive standpoint and that is the size of the pupil. The central portion of the pupil will then, with aberration annulled, lose its superiority, for its focus practically coincides with the foci of the portions more remote from the axis. As a result, therefore, since the focus is somewhat dependent upon the aperture of the system and since the pupil is of varying size, it follows that the refractive condition must be variable and uncertain. It is stated that an emmetrope "by day" will become a myope of approximately one diopter "on the approach of night." ("Emmétrope le jour il devenait myope de environ une dioptrie à l'approche de la nuit.")

X. ASTIGMATISM

98. *General considerations.* It has been previously stated that elementary beams whose rays have but a small inclination to the axis and which proceed from points either on or close to the axis may be brought to a point focus. The beam may be said, therefore, to be *homocentric* in the image space. We shall now consider what will occur when the elementary beam has an inclination to the axis or when the curvatures of the reflecting or refracting surface are different in various meridians.

If a ray of light proceed from a point P off the axis it will not be homocentric in the image space. If a plane elementary beam whose rays in the image space are normal to a certain element e_1 of a line of curvature, then an image will be formed. The image will be located at the center of curvature of this element e_1 since its normals intersect at that point. Since every such element of curvature in a curved surface is intersected at right angles by some other element, e_2, of another line of curvature, a second elementary beam will exist which also produces an image but the positions of the two images do not in general coincide because the curvatures of e_1 and e_2 are usually not identical.

Let *a-b-c-d,* in Fig. 65, represent the four intersections of the four lines of curvature which bound an element of the surface under consideration. Let the curves *ab* and *cd* be horizontal and *ac* and *bd* be vertical. Let the normals at the points *a* and *b* intersect at *a, b;* those at *c* and *d* at *c, d.* Since the arcs *ab* and *cd* have practically the same curvature the points *a, b* and *c, d* lie at the same distance

from the surface *a-b-c-d*. Hence the line l_1 is perpendicular to the ray *S* which passes through the middle of *a-b-d-c* and is normal to it. The normals to any horizontal line of curvature intersect at some point of l_1. Likewise the normals to any vertical line of curvature intersect at some point along l_2 which must be horizontal and at right angles to *S*. These two lines are known as the two focal lines of the beam and the difference between them is called the astigmatic difference. The term *astigmatism* means "without a point or without focus," i. e., an object point cannot give rise to an image point but rather to lines separated by an interval. It is a phenomenon which produces effects similar to those due to spherical aberration; the causes which are operative in the two cases are, however, in general dissimilar, since astigmatic effects are essentially due to curvature changes while spherical aberration arises from eccentric refraction.

Astigmatic images must in general be formed when the elementary

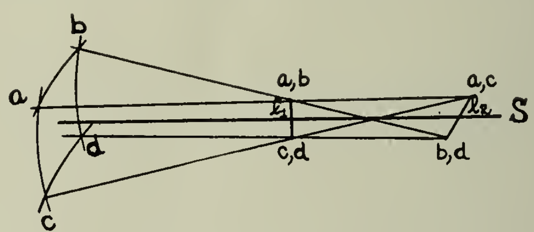


Fig. 65.—An Astigmatic System.

refracting or reflecting surface has two different curvatures. Thus cylindrical lenses, for example, show marked astigmatism.

Reflection or refraction at a spherical surface also renders a homocentric elementary beam astigmatic when the incidence is oblique. In order to consider the case more fully, let the object point *P*, the center of the sphere *C* and the point *A* in which the principal ray of the elementary beam emitted by *P* strikes the spherical surface lie in the plane of Fig. 66. Let the line *PA* be represented by f_1 and the line AP_2 by f_2. Then, since

$$\triangle PAP_2 = \triangle PAC + \triangle CAP_2$$

it follows that

$$f_1 f_2 \sin(\Phi_1 - \Phi_2) = f_1 r \sin\Phi_1 + f_2 r \sin\Phi_2$$

in which Φ_1 and Φ_2 represent the angles of incidence and refraction respectively, and r denotes the radius of the sphere. Since by the law of refraction $n_1 \sin\Phi_1 = n_2 \sin\Phi_2$, it follows from the above equation that

$$\frac{n_1}{f_1} + \frac{n_2}{f_2} = \frac{n_2 \cos \Phi_1 - n_2 \cos \Phi_2}{r} \quad \ldots\ldots\ldots\ldots\ldots\ldots (I)$$

It will be noted that this equation differs from the fundamental equation of refraction at a spherical surface by the introduction of trigonometric functions of the angles of incidence and refraction.

It is evident that all rays from P which have the same angle of inclination a with the axis must, after refraction, cross the axis at the same point P_2. This is known as the *sagittal beam* with a focal point at P_2.

But a meridianal beam, which is one whose rays all lie in the plane PAC, has a different focal point, P_1. Let PB be a ray very close to PA and let its angle of inclination be slightly greater than that of PA,

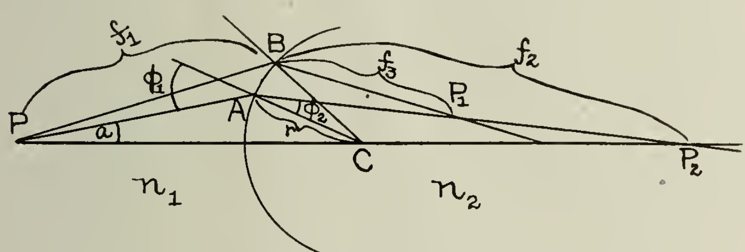


Fig. 66.—Astigmatic Images.

the latter being represented by a. A mathematical calculation of some length (unless calculus is employed) will give the result

$$\frac{n_1 \cos^2 \Phi_1}{f_1} + \frac{n_2 \cos^2 \Phi_2}{f_3} = \frac{n_1 \cos \Phi_1 - n_2 \cos \Phi_2}{r} \quad \ldots. (II)$$

From equations I and II there are obtained different values of f_2 and f_3 corresponding to the same value of f_1. This means that P is imaged astigmatically. This astigmatic difference is greater the larger the obliquity of the incident beam.

The equations for a reflecting spherical surface, which are of value in the deductions relative to the astigmatic errors of various zones of the cornea, can be deduced from I and II by substituting in them $n_1 = 1$, $n_2 = -1$, i. e., $\Phi_1 = -\Phi_2$. Thus for this case

$$\frac{1}{f_1} - \frac{1}{f_2} = -\frac{2 \cos \Phi_1}{r}$$

$$\text{and} \quad \frac{1}{f_1} - \frac{1}{f_3} = \frac{2}{r \cos \Phi_1}$$

and by subtraction,

$$\frac{1}{f_2} - \frac{1}{f_3} = \frac{2}{r}\left(\frac{1}{\cos \Phi_1} - \cos \Phi_1\right)$$

$$\text{or} \quad \frac{f_3 - f_2}{f_3 f_2} = \frac{2}{r} \sin \Phi_1 \cdot \tan \Phi_1 \ldots\ldots\ldots\ldots\ldots\ldots (\mathrm{III})$$

99. *The interval of Sturm.* If a screen is placed near but behind a convex sphero-cylindrical lens, such for example as + 3 D. S. ⌢ + 3 cyl. ax. 90, it will be found that the light from a small brilliant source of light at some distance in front of the lens (the writer uses a small,

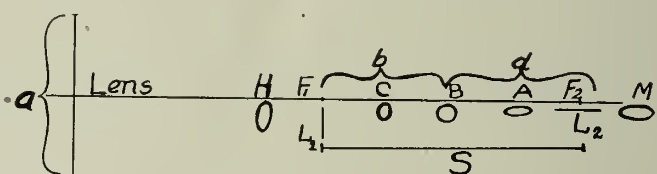


Fig. 67.—The Interval of Sturm.
Circles of diffusion and focal lines of a regularly astigmatic system.

high candle-power incandescent lamp with frosted bulb at 20 feet) will be thrown as a luminous patch on the screen. If now the screen is withdrawn from the lens to a distance of 16.66 cms., which is the focal length of the combined sphere and cylinder, a vertical line will be formed at F_1, Fig. 67. As the screen is moved back still farther from the lens this vertical line gradually changes into a prolate oval at C, into a circle at B, into an oblate oval at A and finally into a straight horizontal line at F_2. The screen is then at the distance corresponding to the focal length of the sphere only; in the illustration given it is at 33.3 cms. The distance between the two foci, F_1 and F_2, of the two sharply defined lines is known as the astigmatic interval or *interval of Sturm.* As the screen is carried still farther from the lens the image formed takes the shape of an ever-increasing horizontal ellipse. The two focal lines are at the focal distances of the two principal meridians and their lengths, represented by L_1 and L_2, are proportional to the diameter, a, of the aperture. A series of relations can be deduced connecting the following quantities:—

F_1 = focus of the first principal meridian.
F_2 = focus of the second principal meridian.
S = interval of Sturm.
L_1 = length of first meridianal line.
L_2 = length of second meridianal line.
D_1 = dioptric value of first principal meridian distance.
D_2 = dioptric value of second principal meridian distance.
B = size of circle of confusion.
b = distance from first focus to circle of confusion B.
d = distance from second focus to circle B.
a = aperture of the lens.
p = distance of B behind the lens.

These relations are:—

(1) $S = F_1 - F_2$

(2) $L_1 \cdot F_2 = L_2 \cdot F_1$

(3) $L_1 = \frac{aS}{F_2} = \frac{aS}{D_1}$

(4) $L_2 = \frac{aS}{F_1} = \frac{aS}{D_2}$

(5) $\frac{d}{b} = \frac{L_1}{L_2} = \frac{F_1}{F_2} = \frac{D_2}{D_1}$

(6) $d = \frac{SF_1}{F_1 + F_2} = \frac{SD_2}{D_1 + D_2}$

(7) $b = \frac{SF_2}{F_1 + F_2} = \frac{SD_1}{D_1 + D_2}$

(8) $d + b = S$

(9) $B = \frac{dL_2}{S} = \frac{bL_1}{S}$

(10) $p = \frac{2F_1F_2}{F_1 + F_2} = \frac{200}{D_1 + D_2}$

Assuming that the average eye has a posterior refractive power of 45 D., and further assuming that the refractive errors are due to curvature, let us calculate the various quantities whose theoretical values have just been written in the case that an eye is myopic 2 D. and 5 D. respectively in the two principal meridians. The aperture of the pupil (a) will be taken as 3.7 mms. lying in the principal refracting plane. The dioptric refracting powers in the two meridians will be, therefore, 47 D. and 50 D. respectively corresponding to focal lengths of 21.5 mms. and 20 mms. When these values are substituted in the foregoing formulæ it will be found that $S = 1.5$ mm., $L_1 = 0.258$ mm., $L_2 = 0.2775$ mm., $\frac{d}{b} = \frac{20}{21.5} = 0.93$ mm. (app.), $d = 0.723$ mm., $b =$

0.7791 mm., B = 0.134 mm., p = 20.723 mms. These calculations are of interest since they evidence: (1) the axial focal lengths corresponding to various refractive conditions, showing approximately 3 D. of error to a change of length of the globe of 1 mm., (2) in astigmatic cases the ratio of the length of horizontal to vertical focal lines is never equal to unity, which means that vertical and horizontal objects of the same size, as for example a square, can never give correspondingly equal retinal images, and (3) if the pupil is larger or smaller L_1 and L_2, as well as B, vary in proportion, hence the larger the pupillary aperture the greater will be the lengths of the focal lines and the size of the circle of least confusion.

100. The following table gives data for the lengths of the posterior and anterior focal lines expressed in millimeters corresponding to an eye of 22 mms. antero-posterior diameter when the degree of astigmatism is expressed in diopters and the diameter of the pupil in mms.

Diameter of Pupil (mm.)	0.1D Anterior Focal line	0.1D Posterior Focal line	0.5D Anterior Focal line	0.5D Posterior Focal line	1D Anterior Focal line	1D Posterior Focal line
1	0.001361	0.001364	0.006781	0.006818	0.01345	0.013636
2	0.002732	0.002728	0.01356	0.01363	0.0269	0.02727
3	0.004083	0.004092	0.02034	0.0245	0.04035	0.04091
4	0.005444	0.005456	0.02712	0.02727	0.0538	0.0545
5	0.00680	0.00682	0.03392	0.03409	0.06725	0.06818
6	0.008166	0.008184	0.04069	0.0409	0.0807	0.08202
7	0.009537	0.009548	0.04733	0.0473	0.0942	0.09545
8	0.010888	0.01091	0.05425	0.0545	0.1076	0.10909

For an astigmatism of 0.1 diopter and for a pupillary aperture of 4 millimeters the length of the focal line is 0.0054 mm. as is shown in the above table. This length of line is very nearly double the diameter of a macular cone. It is thus seen that even a tenth to an eighth of a diopter of astigmatism should diminish the visual acuity when the size of the pupil is about the average, i. e., 4 mms. When the error is 1 diopter, with an average pupil, the lengths of the two focal lines are 0.023 mm. and 0.025 mm. and each of these covers approximately ten distinct retinal elements. A diopter of astigmatism will, therefore, have very distinct influence upon the visual acuity. A cursory inspection of the dimensions of the focal lines and their dimensions relative to the perceptive elements of the retina shows that astigmatism diminishes the acuity when it is as low as a tenth of a diopter. It would, therefore, appear that Donders placed his limit of 1 diopter for physiologic astigmatism considerably too high. It is in fact still a disputed question as to when astigmatism should be considered pathologic in contradistinction to physiologic; the limits have been placed at 0.5 D. to 1.5 D. The foregoing table and similar ones which may be quickly calculated to the first order of accuracy by simply multi-

plying the values given for one diopter by the number of diopters of astigmatic error present, show clearly that the focal lines vary decidedly with the pupillary diameter; hence it is readily conceivable that a larger amount of astigmatism in a particular eye may still give better visual acuity or show less improvement in vision with cylindrical lenses than an eye which has a lesser amount but a larger pupil. A pupillary contraction, therefore, which accompanies accommodation will considerably reduce the errors due to astigmatic images by diminishing the lengths of the focal lines. When the size of the pupil is reduced from 6 mms. to 2 mms. the lengths of the focal lines are reduced in the ratio of 3 to 1 for the two conditions. This explains why astigmates see better under strong illumination. It may with profit be pointed out that, with pupils dilated under the influence of cycloplegics or when examined subjectively in very much darkened rooms, the central astigmatism is replaced by the peripheral astigmatism in the determination of the astigmatic correction and the astigmatism is thereby determined for a portion of the refracting system which does not play a part in ordinary vision when the pupil possesses its normal diameter. This same remark may be made in reference to the correction of axial ametropic conditions, for the circles of diffusion due to large pupils considerably affect the visual acuity, as was pointed out in the section on *Diffused Circles.* It is pertinent, therefore, to call attention to the desirability of obtaining a record of the average pupil in any case under uniform and moderate illumination and to then proceed to the refraction of the eye, either with or without the use of cycloplegics as the practitioner sees fit, screened by an iris diaphragm set a trifle larger than this average or normal pupil size.

101. Fig. 67 gives us further information of everyday value in ophthalmic practice. Suppose that in an eye the first focal line is vertical and the second horizontal and that a single luminous point is viewed. Then the shape of the image on the retina depends upon the position of the retina in the refracted astigmatic pencil (accommodation being eliminated) as follows:—

Position of the Retina	Class of Astigmatism	Retinal Image
At M	Compound myopic	Horizontal ellipse
At F_2	Simple myopic	Horizontal line
At C	Mixed	Horizontal ellipse
At B	Mixed	A circle
At A	Mixed	Vertical ellipse
At F_1	Simple hyperopic	Vertical line
At H	Compound hyperopic	Ellipse

If the retina is in the second focal plane, a horizontal line object is seen distinctly although slightly extended, but a vertical line will be seen blurred. In order that a vertical line be seen clearly the retina must be in the first focal plane. When the retina is between the two focal planes both vertical and horizontal lines will be blurred, the horizontal lines being expanded vertically and the vertical horizontally. Oblique lines will be confused for any position of the retina in such an eye. Hence, in an astigmatic eye the perception of a line is good if the direction of that line corresponds to the direction of the focal line which is at the retina. This explains why astigmatism may be subjectively determined by means of the radiating lines of the clock-dial and other similar tests, and why some of the lines, or chart letters for that matter, are seen more distinctly or sharply than others. Suppose the two principal meridians to be horizontal and vertical. If the retina is situated at or near the horizontal focal line, the confusion discs at the retina correspond in direction to the horizontal retinal image itself so that the edges of the horizontal portions of a test-object are seen sharply and clearly. But the horizontal confusion lines are at right angles to the vertical focal line which will, therefore, cause the vertical portions of the object to appear blurred. If, in turn, the retina is at or near the vertical focal line, the vertical part of the object would be most sharply seen. These conditions are represented in Figs. 68 and 69; Fig. 68 represents the condition in which the retina is at the horizontal focal line. It is a well known principle of optics that the refracting power of a cylinder lies at right angles to its axis; from this it follows that the image of a vertical object is itself vertical, but the power meridian which gave rise to it must have been horizontal. The reverse is the case when a horizontal object is imaged. An astigmatic eye has, therefore, two meridians of power, usually at right angles to each other, and the power meridian which produces any focal line must be at right angles to this focal line. If, for example, in Fig. 67 the retina is assumed to be at F_2 horizontal lines will then be distinctly seen, since the horizontal focal line lies upon the retina at this point; this indicates that the curvature in the vertical meridian of the eye is correct. The focal line at F_1, situated in front of the retina, will be seen blurred and of the form shown in Fig. 69 due to the excessive curvature in the horizontal meridian of the eye. This can be alleviated by reducing the power in the horizontal meridian and would be accomplished in the case in hand by adding a concave cylinder with its axis vertical.

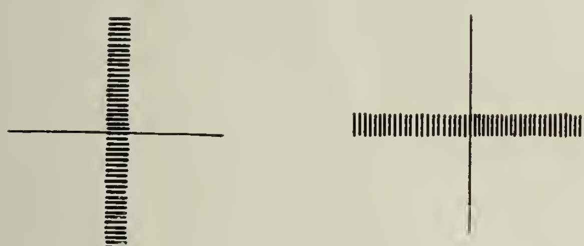
102. The following chief points may be noted:—

(a) The clearest and most indistinct lines of the chart correspond to the focal lines of the eye.

(b) The focal lines of the eye are at right angles to the meridians of which they are the respective foci.

(c) The clearest chart lines correspond in direction to the most ametropic power meridian of the eye; hence the power of the cylinder is needed in that meridian.

(d) The most indistinct lines of the chart correspond to the emmetropic or nearest emmetropic meridian of the eye; hence the rule, as commonly stated, is that the axis of the correcting cylinder should be placed in a direction corresponding to the least distinct (or blurred) lines. Thus, for an eye corrected by a —3 cylinder axis 180°, we see:—(1) the horizontal meridian is emmetropic and the vertical meridian is myopic, (2) the horizontal focal line is in front



Figs. 68 and 69.—Figure 68 Represents the Condition in Which the Retina is at the Horizontal Focal Line: Figure 69 the Condition When the Retina is at the Vertical Focal Line.

of the retina, the vertical focal line is at the retina, (3) the vertical chart lines are seen clearly, the horizontals are blurred and (4) the vertical meridian of this eye requires concave power, i. e., less power than it possesses; the horizontal meridian requires no change in power; the axis of the correcting concave cylinder should be placed along the horizontal or 180° line. It is outside the purview of an article such as this to enter into the various methods and means of testing for astigmatism; the paragraphs penned above and involving some points in the subjective method have been inserted in the hope of making clear the relations between the visual perceptions of test objects, power meridians and directions of axes of correcting cylinders.

103. The foregoing statements also serve to explain why it is that a luminous point when viewed through a Maddox rod (which is simply a very high power cylinder) placed vertically appears as a horizontal streak and, vice versa, with the rod horizontal, a vertical streak of light is obtained. The addition of power to the vertical

meridian of the eye obtained by placing the Maddox rod with its axis horizontal makes the eye artificially myopic in the vertical meridian; the horizontal meridian is unaffected. Assuming for illustrative purposes that the eye is initially emmetropic, it will be seen that the vertical meridian, with the rod placed horizontally, is rendered myopic while the horizontal meridian is left emmetropic. The vertical meridian of the eye under these conditions will, therefore, cause light to converge much more in the vertical direction than does the horizontal meridian in a horizontal direction. The result will be, then, that the retina will receive a vertical ribbon or band of light which, by the laws of projection, will be seen in space as an inverted, upright ribbon or streak of light.

In summary, it may be said that the first focal line is at the focus of the meridian of greatest refraction; it is parallel to the meridian of least refraction; the second focal line is at the focus of the meridian of least refraction and parallel to the meridian of greatest refraction. The diffusion spots are everywhere elliptical except at one point of the interval of Sturm where the luminous spot becomes circular.

104. *Astigmatism of the human eye.* This defect was discovered by Thomas Young in 1801. He used his optometer and measured his astigmatism as the difference in refraction of the two meridians. He had 1.7 D. of astigmatism against the rule. The astronomer Airy was probably the first to correct astigmatism by a cylindrical lens (1827). The invention of the ophthalmometer of Helmholtz and the subsequent measurements of Knapp and Donders drew attention to the prevalency of this defect of the eye. Since that time greater refinements have been made in subjective and objective methods of measuring refractive anomalies and greater accuracy together with the elimination of various errors have been introduced into the mechanical side of ophthalmic lenses. This has meant the correction of astigmatic errors of amounts which were formerly neglected but which, as all practitioners realize, are often highly important in asthenopic conditions. It is rare to find an eye completely free from astigmatism. The chief seat of astigmatism is in the anterior surface of the cornea. Under ordinary circumstances it is the form of the anterior surface that determines the amount and character of the astigmia: the examination of this surface, therefore, plays an important part in the search for astigmatism. A deformity of one of the internal surfaces of the eye has but little influence relatively since there is but little difference in the indices of the internal media of the eye. The refraction of a curved surface separating two media is expressed, as we have shown under

the *Dioptrics of the Eye*, by the relation $\frac{1000\ (n_2 - n_1)}{R}$; that is, for the cornea by $\frac{337.5}{R}$ and for one of the internal surfaces by $\frac{60}{R}$. The same deformity, therefore, existing internally, as might occur at the anterior surface of the cornea, would produce an effect some five to six times less.

105. *Corneal astigmatism.* The corneal astigmatism is measured by means of the ophthalmometer. The essential principles and underlying mathematics of this instrument have been discussed in the paragraphs devoted to the *Catoptrics of the Eye.* In using an ophthalmometer of the usual type one focusses first of all the ocular for the spider thread and then puts the whole instrument in focus for the eye under examination. The images of mires are put in contact in one meridian and its position and power as indicated on the attached drum are read. The instrument is then turned 90° and a similar procedure instituted and the difference indicates the ophthalmometrically determined astigmatism.

Astigmatism "with the rule" is a term often used and signifies that the meridian of greatest curvature does not differ much from the vertical. It is usually specified as lying between the limits of 45 degrees on each side of the vertical. Astigmatism "against the rule," sometimes designated as "inverse" or "perverse" astigmatism, indicates that the horizontal meridian has the greater refraction. Various tables of statistics showing the percentage of different classes of astigmatism may be found in numerous treatises upon the eye: in general, these tables show about 80 per cent. of all astigmatism as being "with the rule" and not in excess of 5 to 10 per cent. "against the rule." This frequency of astigmatism with the rule, demanding for the correction thereof plus cylinders at axis 90° or minus cylinders at axis 180° or within 45° thereof, thus indicating that the vertical meridian possesses the greater refractive power, may be accounted for by reason of the anatomical structure of the eyeball and of the orbit, and by the action of the lids and the insertion and operation of the extra-ocular muscles.

106. Fig. 70 is a presentation of the curvatures of a centrally non-astigmatic eye at various points of the cornea. After having measured with the aid of the ophthalmometer the refraction of the two principal meridians at the point of intersection of the visual line with the

cornea, the eye is caused to fix points 5°, 10° ...... to 30° in the temporal, nasal, superior and inferior directions. The curvatures are measured in the two principal meridians with the eye deviated through these various angles 5° at a time. By taking into account the spherical aberration (since the calculations are to be made for incident rays parallel to the visual line), the astigmatism of these various 5° zones of the cornea which are concentric with the point of intersection of the visual axis and the cornea can be determined.

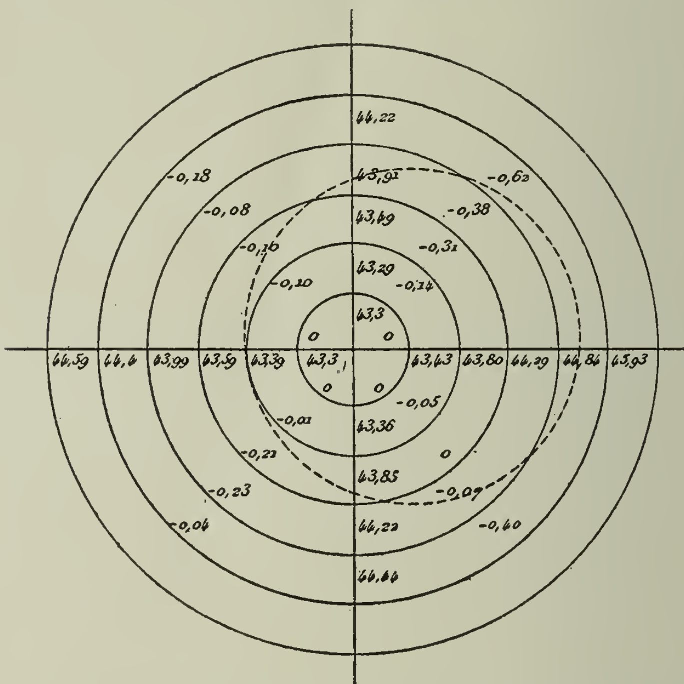


Fig. 70.—Cornea Without Central Astigmatism but Having Peripheral Astigmatism Against the Rule.

The results of a large number of such experiments upon both astigmatic and non-astigmatic eyes show:

(1) The peripheral portions of the cornea possessing no central astigmatism show an "inverse" or "against the rule" astigmatism.

(2) The peripheral portions of an astigmatic cornea showing weak "with the rule" conditions will indicate either no astigmatism or weak astigmatism "against the rule."

(3) When the central portion shows astigmatism "against the rule," the peripheral portions will show the same except to a higher degree.

(4) The peripheral portions of a cornea having astigmatism "with the rule" of moderate or high amount are oft-times much more astigmatic than the center, and again at times less astigmatic.

The differences between the central and peripheral portions of the cornea are bound up with spherical aberration and with the condition that either the meridian of greatest or least curvature flattens out very rapidly as one passes from the center to the corneal periphery.

107. *Astigmatism by incidence.* It is known that the various refracting surfaces of the eye are not generally accurately centered. Defects due to this lack of exact centering are generally small in that they produce little astigmatic error except in cases of pathological

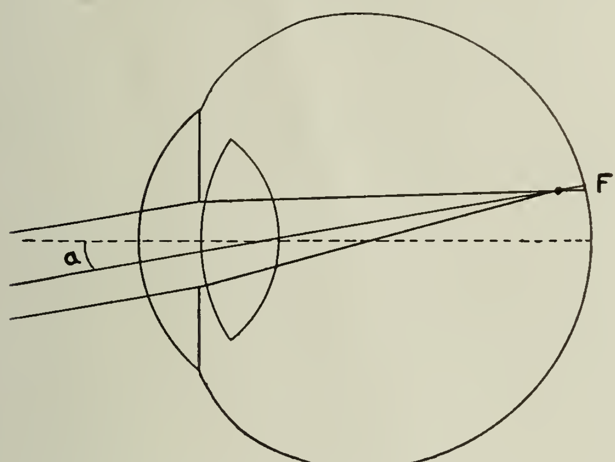


Fig. 71.—Astigmatism by Virtue of the Angle Alpha.

luxation of the lens. The pupil is ordinarily exactly centered with respect to the axis of the system; but the object "fixed" is not upon this line. This condition we have previously discussed and designated as the *angle alpha* which has ordinarily a value of about 5° but may be greater or, in some cases, negative in value. Even though the incident beam along the optic axis should be devoid of astigmatism, it will not be true of the beam emanating from the object and passing along the visual axis. This is illustrated in Fig. 71 which is a horizontal cross-section of the right eye and shows the astigmatism due to incidence by virtue of the angle alpha. The optic axis is deviated outwardly and downwardly with respect to the visual line. Since the meridian passing through the axis is most powerful refractively, the astigmatism produced by the angle alpha is inverse or against the rule,

the meridian of greatest refraction now being horizontal and slightly inclined temporal-ward. If D denotes the refractive power of the meridian of greatest refractivity and i the angle of incidence, the degree of astigmatism is equal to $D\ (1 - \cos^2 i)$. The values of the astigmatism in diopters corresponding to various values of the angle alpha calculated for an average eye are as follows:

	Diopter 1°	3°	5°	7°	8°	9°	10°
Corneal astigmatism.......	0.02	0.13	0.35	0.66	0.86	1.11	1.35
Lenticular astigmatism.....	0.01	0.05	0.14	0.26	0.35	0.44	0.54
Total astigmatism.........	0.03	0.18	0.49	0.92	1.21	1.55	1.89

By virtue of this angle alpha an inverse astigmatism arises which is, on the average, about one-half to three-quarters of a diopter but may reach values as high as 2 D.

108. *Astigmatism due to lens obliquity.* Another form of astigmatism due to incidence may be designated as astigmatism due to lens obliquity. It can be mathematically demonstrated that when a spherical lens is rotated about any diameter there will be produced by this obliquity of the spherical lens a slightly stronger sphere coupled with a cylinder whose axis corresponds to the axis of rotation. This condition is referred to under the name of *oblique centric refraction.* The formulæ for the cylindrical effect of oblique sphericals are usually given in a complex form (see for instance their development in A. S. Percival's *Optics,* pages 270-281), but the simple relations which follow in the next sentence may be found in Laurance's *General and Practical Optics.* If F represent the focal length of the lens, and F_1 and F_2 indicate the effective focal lengths of the meridians of greatest and least power, while a represents the angle of incidence, it can be shown that

$$F_1 = F_2 \cos^2 a$$

$$F_2 = \frac{F\ (3 - \sin^2 a)}{3}.$$

Thus, for example, if the crystalline lens *in situ* has a power of 16.66 D. and it should be tilted about the horizontal axis and at right angles to the axis of the ocular system by an angular amount of 10°, then F will be found to be 6 cms., F_2 to be 5.938 cms. and F_1 to be 5.758 cms. or approximately $D_1 = 17.36$ diopters and $D_2 = 16.82$ diopters. This is equivalent as a sphero-cylinder to 16.82 D. S. $\bigcirc$ + 0.50 cyl. ax. 180 practically. We have, therefore, by the tilting of the crystalline lens by an angular amount of 10 degrees produced an increased spherical

power of about $\frac{1}{6}$ D. coupled with a $\frac{1}{2}$ D. cylinder. Savage, in the chapter on the muscles of the ciliary body in his book on *Ophthalmic Myology,* discusses at some length the probable functions of the Mueller's muscle and the Bowman's muscle. He presents excellent reasons for believing that the former is concerned largely with the accommodative changes while the Bowman's muscle, which consists of the meridianal fibers, is actively concerned in the placing or holding in position of the lens. It does not appear improbable, therefore, that in the process of the development of an eye the lens may assume its mathematically correct position; but if it does not the Bowman's muscle, under the guidance of the retinal sensations, may come to its assistance. It may also happen that a corneal astigmatism may be in part or wholly offset by a lenticular condition or tilting of the lens such as that just discussed through the agency of the action of the individual fibers of Bowman's muscle.

Savage cites his own personal case in the emphasis of two points:—(1) there was a lenticular astigmatism that almost completely neutralized the corneal astigmatism for a considerable number of years, the final full corneal astigmatic correction, as originally determined by the ophthalmometer, being eventually given and worn and (2) the power that affected the neutralizing lenticular astigmatism was not suspended by the repeated use of mydriatics. The logical conclusion seems to be that the lenticular astigmatism was produced by fibers of Bowman's muscle. "If the tilting of the lens by contraction of a single portion of Bowman's muscle is not the cause of the lenticular astigmatism, the simultaneous and equal action of two opposite parts of Bowman's muscle, by making these the corresponding parts of the zonula, could so compress the part of the lens intervening as to increase its refractive power, thus effecting lenticular astigmatism."

109. *Astigmatic accommodation.* It is pertinent to discuss in this connection the question of astigmatic accommodation. Dobrowolsky first expressed the idea that astigmatic persons could partly correct their defect through an irregular contraction of the ciliary muscle, thus producing a deformity of the crystalline lens in the opposite direction. G. Martin, Vacher, Clarke and others have attributed to astigmatic accommodation a train of pathological conditions, including keratitis and cataract. Eriksen, Sulzer and George Bull do not admit astigmatic accommodation. The basis for the belief in astigmatic accommodation lies in the change of the astigmatism observed on instilling atropine. The phenomenon is doubtless due in part to the differences in the astigmatic conditions at the peripheral and central zones of the pupil, a topic which has been discussed in preceding paragraphs.

Again, suppose the diameter of the pupil is brought from 4 mms. to 8 mms. The area increase in one condition over the other is about 40 sq. mm., or triple the pupillary area of the original 4 mm. pupil. Thus much more light enters through these peripheral parts and, as Tscherning says, "It is not surprising that this fact greatly influences the answers of the patient." Likewise the researches of Savage indicate that atropine has little or no effect in suspending lenticular astigmatism and that this power could not have been derived through the fibers of the third nerve supplying the ciliary. On the other hand, Lucien Howe (*Muscles of the Eye*) points out several facts indicating that such contraction of the ciliary process does occur. These are briefly as follows: (1) It is entirely possible from the anatomical arrangement. (2) Measurements of contraction in other muscles show that there is frequently a difference in degree of tension in different fibers. (3) It is probable that part of the filaments which go to the ciliary muscle may be in a normal condition, while others may be partially paretic or insufficient or, again, over-active, thus producing irregular action on the zonula. (4) Subjectively no astigmatism may be evidenced, the vision being 20/20 easily, while all objective tests show the presence of a decided astigmatism, indicating an astigmatic accommodation. (5) The clinical experience that the correction of an objective astigmatic condition lessens discomfort and ocular headaches, although no improvement of the vision may result.

110. *Frequency of astigmatism.* The frequency of low amounts of astigmatism against the rule, commonly found as plus cylinders axes 180° or close thereto, in persons over 40 years of age on, cannot have escaped the notice of practitioners. Faehndrich has given us the following curves showing the relative frequency of "with" and "against the rule" astigmatism with age. These results are shown in Fig. 72. From 40 years on throughout the presbyopic period astigmatism against the rule is found in increasing percentages, reaching about 80 per cent. at 70 years of age. The writer believes that this inverse astigmatism is, in the majority of cases, a lenticular condition or condition of lens situation due to increasing obliquity of the lens with weakened powers of the Bowman muscle because of increasing years and because of their possible abnormal development in certain directions due to visual habits. It is to be remembered that the gaze is rarely fixed upon objects in the primary isogonal or straight-away position or inclined upwardly but rather is it inclined downwardly in all the ordinary demands upon vision. This means a rotation of the eyeball slightly downward for a greater portion of one's working hours and therefore a slight tension, presumably through the medium

of Bowman's muscle, to keep the crystalline properly placed; that is, to prevent its assuming a partially perpendicular position rather than a properly centered one with respect to the remainder of the system. It seems plausible, then, to believe that visual habits should cause a development of small astigmatic errors against the rule due to tilting of the lens. It is possible, also, that the supposed decrease of myopia with increase of years beyond the fiftieth year may be explained not only by the contraction of the pupil with age and by the acquisition of hyperopia presumably due to increased density of the cortical layers of the crystalline lens, but in many cases there may be the additional factor of the increased spherical power produced by lens obliquity.

We are not, however, to suppose from these remarks that the seat of this astigmatism against the rule may not be in the posterior surface

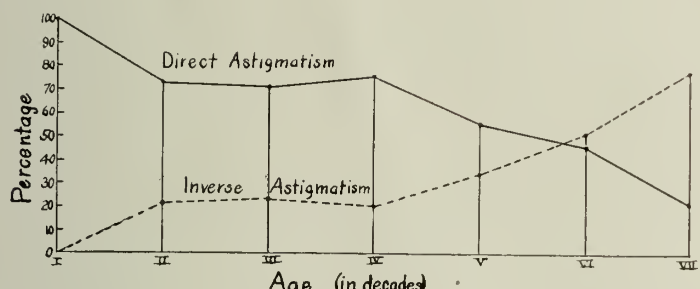


Fig. 72.—Relative Frequency of "With" and "Against" the Rule Astigmatism According to Age. (After Faehndrich.)

of the cornea. In fact it seems possible to successfully and rapidly locate the seat of such errors. For if the ophthalmometer indicates no astigmia and the subjective and skiametric methods show its presence, the skiametric shadow being practically uniform in its motion in any specified meridian and that, too, in various portions of the pupil, we may ordinarily attribute the defect to the posterior corneal or anterior crystalline curvatures. But if retinoscopically, the examination being made along the visual axis, the skiametric reflex divides into two portions, one of which indicates hyperopic and the other myopic corrections, thereby exhibiting the so-called *"scissor movement,"* one may consider the crystalline lens obliquity as being one of the factors, to say the least, if not the only one to be considered.

111. *Astigmatism due to the forms of the ocular surfaces.* It has been found experimentally that about 70 per cent. of all corneas show an astigmatism varying from 0.5 D. to 1 D.; this is, as a rule,

the degree of astigmatism given by the anterior corneal surface. But little is known of the *posterior surface of the cornea.* This surface appears in general to possess a much greater curvature in the vertical than in the horizontal meridian. It is a deformity analogous to that which, if lying in the anterior corneal surface, would produce astigmatism with the rule. Since the posterior corneal surface is concave, i. e., acts like a concave lens, it may often happen that this difference in curvatures produces an ''against the rule'' astigmatism of a quarter to a half diopter. This doubtless explains why—in many cases having subjective astigmatism—we find no ophthalmometric astigmia.

The measurements of three eyes representing (I) astigmatism with the rule, (II) against the rule and (III) practically nil, as made by Tscherning with his ophthalmophakometer, are inserted at this point; the symbol *''d''* represents direct astigmatism while *''i''* indicates the inverse condition.

	I	II	III
Anterior Surface of Cornea			
Horizontal radius (mms.)......	7.98	7.78	8.29
Vertical radius	7.69	7.90	8.33
Astigmatism (diopters)	2.4(*d*)	0.8(*i*)	0.22(*i*)
Posterior Surface of Cornea			
Horizontal radius (mms.)......	6.2	5.7	6.2
Vertical radius	5.0	5.1	5.9
Astigmatism (diopters)	—0.6(*d*)	—0.6(*d*)	—0.2(*d*)

Tscherning says:—''Although we manifestly cannot draw general conclusions from the measurements of three eyes, I wish, however, to direct attention to some of these results. We observe in the first place that the vertical meridian of the posterior surface of the cornea presents a more pronounced curvature than the horizontal meridian. This condition is repeated in the three eyes to which I here refer, as well for the first, the anterior surface of which presents astigmatism with the rule, as for the other two in which it presents astigmatism against the rule. I have also met the same deformity in other eyes which I have measured, so much so that there is reason to believe that the condition is general.''

112. Tscherning, Stadfeldt and Awerbach have made measurements upon the crystalline lens using the ophthalmophakometer. The vertical and horizontal meridians were measured but no attempts were made to actually determine the principal meridians. The (+) sign indicates astigmatism with the rule and the (—) sign shows inverse

astigmia in the following selected portions of data obtained from some sixteen different crystalline lenses examined by these experimenters.

Crystalline Astigmatism in Diopters

Anterior surface.	+ 0.1	+ 0.7	+ 0.5	+ 0.3	+ 0.8	+ 0.3	+ 0.5	+ 0.8
Posterior surface	— 0.1	— 1.8	— 0.3	+ 0.2	— 1.1	— 1.2	— 1.5	+ 1.4
Total	0	— 1.1	+ 0.2	+ 0.5	— 0.3	— 0.9	— 1.0	+ 2.2

The anterior surface of the crystalline in all cases examined showed a direct astigmatism while the posterior surface often exhibited the inverse type. Judging from the limited data at hand it appears that the crystalline surfaces are more spherical in form than the cornea. We can express the refractive power of a spherical surface by $\frac{1000\,(n-1)}{R}$. For the cornea the factor $1000\,(n-1)$ has a value of 337.5 and for the crystalline it is approximately 74. A certain deformation of the cornea will, therefore, produce an effect four or five times as great as the same deformation in one of the crystalline surfaces. The astigmia of the normal cornea being about 0.5 D. to 0.75 D., the crystalline surfaces will not, therefore, show more than 0.1 D. to 0.2 D. astigmatism if they are as regular as the corneal surfaces. The results of Awerbach, Stadfeldt and Tscherning in a general way support this conclusion.

113. *Post-operative astigmatism.* An examination of a cornea soon after a cataract operation shows a large amount of astigmatism against the rule. This is sometimes as high as 15 diopters. The vertical meridian is considerably flattened, probably due to the interposition of an exudation between the folds of the incision; the phenomenon is more pronounced if there is a hernia of the iris. This astigmatism gradually diminishes and generally reaches a final value of 1 to 2.5 diopters.

Post-operative astigmatism is due, according to Treutler, both to vertical flattening and to increase in the horizontal curve. In some cases the astigmatism, found a month after operation, persists or is even increased: in other cases it diminishes somewhat and disappears in a few months. This reduction may be attributed to readjustments of wound surfaces; in sclero-corneal sections it may be that the closer growth of epithelium interposes a wedge between the edges of the wound. Jackson found that in fifteen per cent of cases a permanent degree of astigmatism was reached within two months of operation: in about twenty-five per cent regressive changes continued after more than three months. Rollet, in 150 cases, found that five months after

the operation twenty-five per cent exhibited no marked astigmatism, while the remainder had an average amount of 2.57 diopters. A year or more after the extraction there was either a complete disappearance of the astigmatism or a small amount developed at right angles to the original directions.

114. *Keratoconus and irregular astigmatism.* The highest degrees of corneal astigmatism are met with in conical cornea, excepting post-operative results following immediately after cataract extraction. The apex of the cone does not in general coincide with the visual line. This gives rise to a strong astigmatism the direction of which varies. An ophthalmometric examination shows the images of the mires in irregular forms and often so confused that they cannot be brought into line. When the curvatures of the central and peripheral zones of the cornea are markedly different yet symmetrical, strong spherical aberration rather than irregular astigmatism is essentially produced. Irregular corneal astigmatism is generally considered to be a result of wounds or ulcers, although it may be congenital or spontaneously acquired. There is no *complete* correction for irregular astigmatism, although vision may be aided by spheres or cylinders or their combination. Aid can also be given by stenopaic spectacles in the form of slits or small apertures. The only true remedy would consist of a cell of water, the liquid being held in contact with the cornea by means of a thin spherical shell. Irregular lenticular astigmatism may be caused by iridic adhesions thus producing irregularities of the lens capsule. It may also result from change of density, refractive index, or a deformity of shape or position may exist congenitally or as the result of a condition such as incipient cataract. It may, again, be caused by differences in the refractive indices of the vitreous, possibly due to the presence of sugar.

115. A particularly interesting type of irregular astigmatism is one which arises from the circumstance that the two principal meridians of the cornea are not at right angles to each other, or practically so. Such cases demand as correcting lenses a combination of two cylinders at oblique axes which can be transposed over into equivalent sphero-cylinders by the methods of Donders, Jackson, Weiland, Prentice or Sheard. Such cases can perhaps be most successfully handled by the employment of a 1 mm. stenopaic slit and determining thereby the meridians or positions of the slit giving best and poorest vision. Each meridian having been corrected in turn to give as nearly 20/20 vision as possible, the complete findings are inserted in the trial frame after making the calculations for the equivalent sphero-cylinder

and the axis of the cylinder determined either mathematically or by subjective testing only.

It is to be said by way of introduction that prescriptions involving cylinders crossed at oblique axes are rarely encountered, and it may likewise be stated that such corrections, when found, are often due to lack of skill and technique on the part of the practitioner; they do exist, however, and when they do must be classed as cases of peculiar irregular astigmatism due to corneal defects (ectasia corneæ), such as conical cornea or displacement or turning of the lens (ectopia lentis).

It is not feasible within the limited space of this article to develop the mathematical theory of the dioptric formulæ for combinations of cylinders with axes at any angular deviation. This has been admirably done by C. F. Prentice, M. E., in his work on *Ophthalmic Lenses* and in the section on **Lenses** published in Volume X of this *Encyclopedia*, and again by the writer of this article in a brief and possibly much simplified form in the *Physical Review* in 1914. In succinct form the equations as developed by the writer are:

(1) $X = d_1 \cos^2 \theta_1 + d_2 \cos^2 \theta_2$,

(2) $Y = d_1 \sin^2 \theta_1 + d_2 \sin^2 \theta_2$,

(3) $A + B = X + Y$,

(4) $A \cdot B = d_1 d_2 \sin^2 \gamma$.

(5) $(B - A) \cos 2\delta = Y - X$.

The symbols have the following significances:

d_1 = dioptric power of first cylinder of the oblique-angled combination.

d_2 = dioptric power of second cylinder of the oblique-angled combination.

A = dioptric power of first cylinder of cross-cylinder combination.

B = dioptric power of second cylinder of cross-cylinder angled combination.

X = total dioptric power in the horizontal direction due to the two members of the oblique axis combination.

Y = total dioptric power in the vertical direction due to the two members of the oblique axis combination.

γ = angle between axis of the oblique combination.

δ = angle which one member of the right-angled equivalent combination makes with the horizontal line, $0° - 180°$ line.

θ_1 = angle which first member of oblique combination makes with the $0° - 180°$ line.

θ_2 = angle which second member of oblique combination makes with the $0° - 180°$ line.

Fig. 73(A) is inserted in order to aid the reader of this treatise in mentally placing the various angles and powers involved. No importance is to be attached to the actual dimensional values of the geometrical functions involved in this diagram; the drawing is inserted solely for illustrative purposes.

In the solution of equations (3) and (4) it will be found that there are two numerical values which satisfy A and likewise two satisfying B. When these results are substituted in equation (5), the angle δ will be found to have a positive value when one set of values of A and B is used and a negative or minus value, algebraically considered, when the second set of values of A and B are used. A general rule

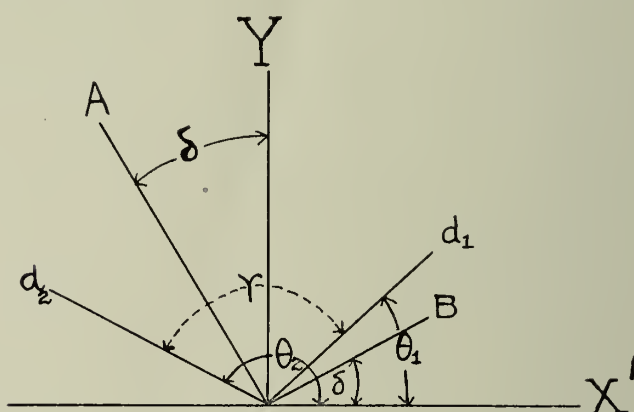


Fig. 73.—(A). Explanatory of Symbols Used in the Theoretical Development of the Equivalence of Cylinders Crossed at Oblique Axes.

relative to the angles at which the two members of the equivalent cross-cylinders are to be placed may be formulated as follows:—

If the solution of the equation $(B - A) \cos 2\delta = Y - X$ gives a positive value to the angle δ, then the cylindrical value of A used in the solution of this equation is to lie with its axis at the angular position indicated by δ; if the solution of the equation gives a negative value to the angle δ, cylinder B lies at that angle.

In addition, complications will be avoided when the two cylinders at oblique axes have different signs if they are transposed first of all into an equivalent sphere combined with the two cylinders which should now have the same algebraic signs but one of the axes changed by 90°.

An illustrative case will show the operative and mathematical procedure. O. D., stenopaic slit used; slit position at 55°, vision sharpest;

slit position 165, vision poorest. + 2 D. S., slit at 55°, gave V = 8/10 and — 4 D. S., slit at 165, produced V = 8/10. The prescription as a double cylinder at oblique axis is, then, + 2 cyl. ax. 145° ⊂ — 4.0 cyl. ax. 75°. The angles θ_1, θ_2 and γ are known; they are 145°, 75°

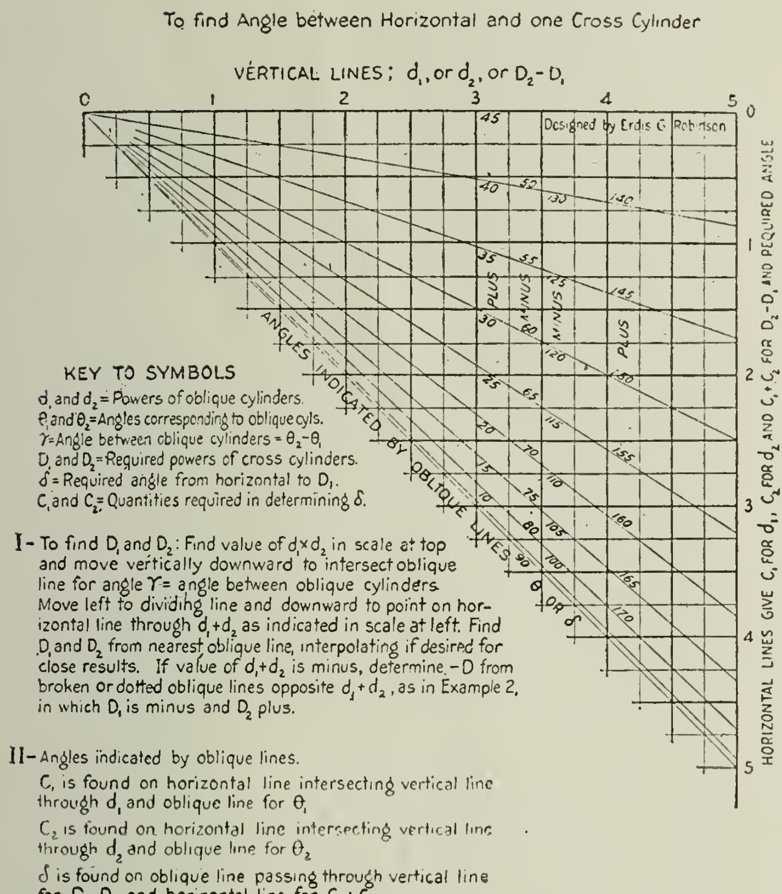
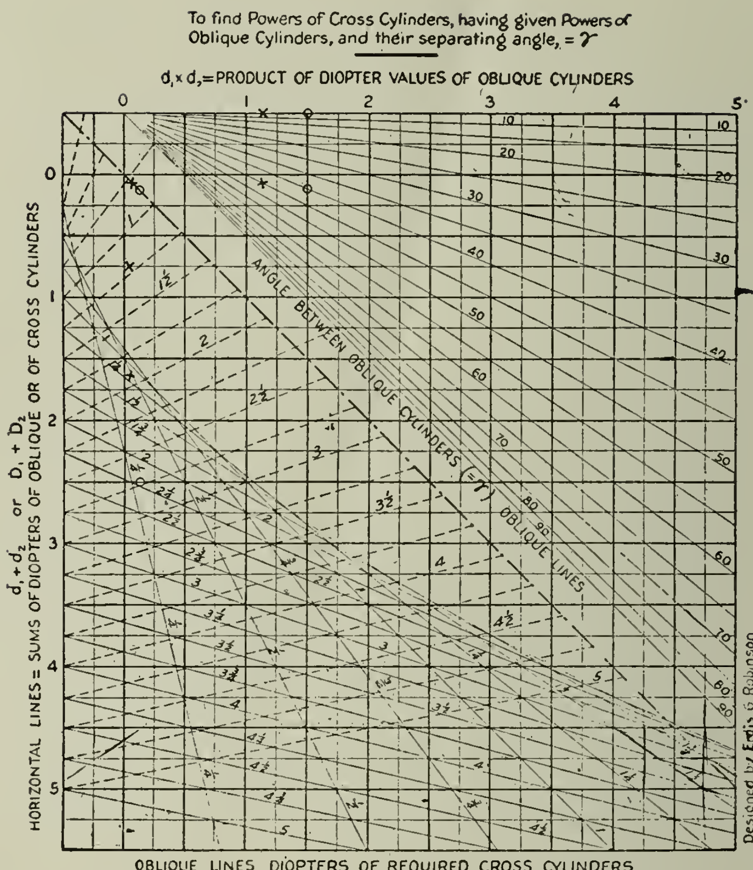


Fig. 73.—(B). Chart for Obtaining the Equivalence of Cylinders Crossed at Oblique Axes.

and 70° respectively. From equations (1-4) the value of $A = +1.839$ or -3.839 and $B = -3.839$ or $+1.839$, and the value of angle δ from equation (5) is practically 22°. This gives as a cross-cylinder combination, therefore, + 1.839 cyl. ax. 22° ⊂ — 3.839 cyl. ax. 112° or — 3.839 D. S. ⊂ + 5.678 cyl. ax. 22. From the data recorded in the files in connection with the case being described we find that — 3.75



EXAMPLE I – Transpose into equivalent cross cylinders + 1.50 cyl. axis 120° ⊂ 1.00 cyl. axis 80°. Solution on charts indicated by small circles, O. We have $d_1 = 1.50$, $d_2 = 1.00$, $d_1 \times d_2 = 1.50$, $d_1 + d_2 = 2.50$, $\gamma = 40°$. Enter CHART I at top for $d_1 d_2 = 1.50$ and move vertically downward to oblique line for 40°; then to left to Dividing Line (—·—) and down to point horizontally to right of $d_1 + d_2 = 2.50$. Read from nearest oblique lines the values of D_1 = 0.30 D, and D_2 = 2.20 D. Enter CHART II at top for $d_1 = 1.50$, and move downward to intersect oblique line for θ_1 = "120° minus" and from scale at right read $C_1 = -0.75$. Likewise find $C_2 = -0.95$, and $C_1 + C_2 = -1.70$. From values found by CHART I, $D_2 - D_1 = 1.90$. Enter CHART II again and find δ, the required angle = 15° on oblique line intersecting vertical through $D_2 - D_1 = 1.90$ on top scale, and horizontal through $C_1 + C_2 = 1.70$ in scale at right. Hence required solution 0.30 cyl axis 15° ⊂ 2.20 cyl. axis 105°.

EXAMPLE 2 – Solution indicated by small cross X. Transpose +0.75 cyl. axis 135° ⊂ −1.50 cyl axis 180°. $d_1 = 0.75$; $d_2 = -1.50$, $d_1 d_2 = -1.12$, $d_1 + d_2 = -.75$; $\gamma = 45°$. CHART I gives $D_1 = -1.20$, $D_2 = 0.45$. CHART II gives $C_1 = 0$, $C_2 = 1.50$, $C_1 + C_2 = 1.50$, $\delta = 13°$. Solution −1.20 cyl. axis 13° ⊂ 0.45 cyl. axis 103°.

Fig. 73.—(C). Chart for Obtaining the Equivalence of Cylinders Crossed at Oblique Axes.

D. S. ⊂ + 5.75 cyl. was introduced into the trial frame and the axis of the cylinder subjectively found to be best at 175°. The final lens values determined upon differed but slightly from the calculated values; the monocular "best-acuity" finding was —3.50 D. S. ⊂ + 6.00 cyl. ax. 175°. The question of the disagreement of axes of cylinders as subjectively determined and mathematically calculated is discussed in a paper by the writer in the *Ophthalmic Record,* Vol. XXV, pages 558-567, 1916.

Some of the important points to which attention may be directed in the handling of cases involving bi-cylindrical corrections are the following:—(1) The use of the narrow stenopaic slit for the determination as accurately as possible of the best and poorest visual meridians and the attainment of the highest visual acuity in each meridian by the use of spheres according to the customary methods. (2) The preliminary mathematical determination of the values of the two cross-cylinders, which should be converted into equivalent sphero-cylinders and substituted in the trial frame; determine subjectively the best position of the cylinder and finish the test. (3) This method of procedure precludes the possibility of a prescription involving a sphere in combination with two oblique cylinders. (4) The advantage to the practitioner of having the final form of sphero-cylindrical correction before his patient's eye and the nicety of adjustment of the cylinder thus permitted. (5) The fact that equivalent sphero-cylindrical corrections are not equally acceptable warrants the use, in turn, of each form of correction in order to select that which is most satisfactory all points being considered.

Mr. Erdis G. Robinson, C. E., of Columbus, Ohio, has given graphical methods of determining solutions of equations (1-5). These are inserted as Figs. 73 (B) and 73 (C) together with his explanatory notes and directions.

116. *Relations between corneal and total astigmatism.* Quite a difference is often found between the ophthalmometric and subjective measurements. This was first pointed out by Donders and Knapp who attributed this difference to an astigmatism of the crystalline which would act in a contrary direction to that of the cornea. Javal, Pflüger, Tscherning and others have investigated the relations between corneal and total subjective astigmatism. The curves in Fig. 74 are due to Javal and Pflüger; the ordinates represent the amount of astigmatism in diopters. Javal employed concave and Pflüger convex cylinders exclusively. Hence the differences in their cylindrical lens corrections for various ophthalmometric determinations is due in part to the effectivity of plus and minus lens corrections situ-

ated at a certain distance from the eye; the reader is referred to the discussion on vertex refraction and to the effectivity of lenses in the correction of myopia and hyperopia given in previous paragraphs and to treatises on ophthalmic lenses (see particularly Landolt's *The Accommodation and Refraction of the Eye*). Quite apart from physiological reasons, then, apparent changes in the astigmatism of the eye as a whole may arise from optical sources. There is a change due to effectivity as the cylinder is placed in advance of the cornea and as it is convex or concave. This causes the subjective determination of astigmia to differ from the ophthalmometric so that, for example, 4 diopters of corneal astigmatism is corrected by a — 4.25 D. cyl. or a + 3.75 D. cyl. when placed 15 to 17 mms. from the cornea.

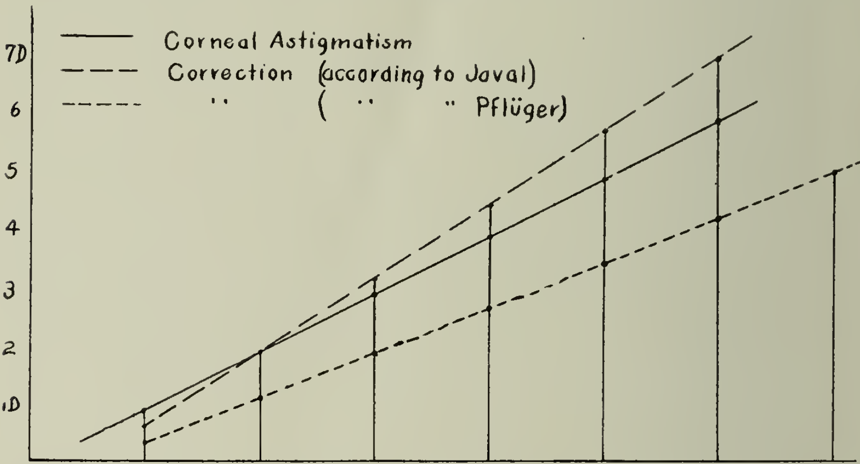


Fig. 74.—Corneal Astigmatism and Lens Connections According to Javal and Pflüger.

There is likewise a change of the astigmatic value of any cylinder as this is combined with a sphere. For this reason a degree of astigmia measured in the eye or at the cornea by keratometric methods is different than the power of the cylinder which will correct it when the latter is combined with a spherical. Suppose, for instance, that there is found 4 D. of actual corneal astigmatism; there will then be required, if one meridian of the eye is emmetropic, a cylindrical lens of focal power + 3.75 D. or — 4.25 D.: if, however, one of the meridians of an eye is hyperopic 6 D. and the other is hyperopic 10 D., the focal lengths of the lens would need to be (at 15 mms. from the cornea) 166 + 15 = 181 mms. and 100 + 15 = 115 mms. or powers of 5.50 D. and 8.75 D., that is + 5.50 D. S. ⌒ + 3.25 cyl. In this case then 4 D. corneal astigmatism would be corrected by a + 3.25

cylinder when in combination with the specified sphere. These conditions may be transposed, however, and the meridians of an eye corrected in the reverse order, i. e., as though the correction were fundamentally 10 D. ⊃ — 4 D. The focal lengths of the lens would then be $100 + 15 = 115$ mms. and $-250 + 15 = 235$ mms. or powers of $+ 8.75$ D. and $- 4.25$ D., that is to say, $+ 8.75$ D. S. ⊃ 4.25 cyl. ax. $(x + 90°)$ if the plus ⊃ plus combination as just calculated has its cylindrical element at axis "x."

Furthermore, there are the reports of John Rowan (*British Medical Journal*, 1912) in which the astigmatism in one thousand eyes was measured, first by the ophthalmometer of Javal and Schioetz and then by retinoscopy, with atropin or homatropin as cycloplegic. The results of his measurements show that, out of the one thousand eyes examined, *the total astigmatism and the corneal astigmatism were the same* in 475 cases, or 47.5 per cent. This is certainly an interesting conclusion and comes as a rather brisk rejoinder to those who minimize the value of the ophthalmometer in ocular refraction.

117. The rules of Javal, commonly accepted by most investigators, are:—

(1) If there is no ophthalmometric astigmatism, we generally find a slight subjective astigmatism against the rule.

(2) If the ophthalmometric astigmatism is against the rule, the subjective astigmatism is usually against the rule and of greater amount.

(3) If the ophthalmometric astigmatism is with the rule and of a value intermediate between 1 and 3 D., the subjective astigmatism generally differs only slightly from it.

(4) If the ophthalmometer gives an astigmatism with the rule and greater than 3 D., the subjective astigmatism is also with the rule and frequently greater.

Javal expressed the difference between the subjective astigmatism (As_s) and the ophthalmometric astigmatism (As_c) by the empirical rule that

$$As_s = k + p \cdot As_c$$

in which k and p are two constants, $k = 0.5$ D. against the rule and $p = 1.25$. The formula gives the following relations:—

	Against the rule			With the rule					
Ophthalmometric astigmatism..	2	1	0	1	2	3	4	5	6
Subjective astigmatism........	3	1.75	0.5	0.75	2	3.25	4.5	5.75	7

118. Among the factors which may be mentioned which may account for these differences are:—

(a) *Deformity of the internal surfaces.* The vertical meridian of

the posterior surface of the cornea presents a more pronounced curvature than the horizontal meridian, whether the condition in toto is one of astigmatism with or against the rule. It is doubtless for this reason that eyes which have no ophthalmometric astigmatism generally have subjective astigmatism against the rule. The term k of Javal's formula must be influenced in part by the posterior surface of the cornea.

(b) *The obliquity of the crystalline lens.* This produces astigmatism against the rule which may be compensated in large measure by the special structure of the crystalline lens (Hermann). This compensation due to crystalline structure, as hypothecated by Hermann and some other investigators, is open to serious criticism however.

(c) *The influence of the distance of the correcting lens from the eye.* In consequence of this the concave correcting cylinder is stronger and the convex weaker than the true astigmatism.

(d) *Astigmatic accommodation of the lens.* This would have the effect, if such an action is possible, of correcting in part or in whole—or even over-correcting—the corneal deformity.

(e) *The astigmatism in the different zones of the cornea.* The peripheral zones frequently possess a value and sometimes a direction more or less different from those of the central zone.

These factors are merely pointed out in concluding this discussion of astigmatism; they have been considered at some length in the preceding paragraphs.

XI. ENTOPTIC PHENOMENA

119. If one approaches a luminous point the circle of diffusion to which it gives rise increases in size; when the luminous point is at the anterior focus of the eyes the rays are parallel after refraction and the circle of diffusion is equal to the size of the pupil. Entoptic phenomena are then observed; that is to say, shadows which the "corpuscles," as Tscherning calls them, or particles situated in the various refracting media of the eye, project upon the retina can be rendered visible to the eye itself. Thus opacities and normal striæ in the crystalline lens and those due to cataract can be seen by looking at a surface, such as a white cloud, through a pin-hole disc placed at the anterior focus of the eye. Another method of observing entoptic phenomena is to look at a luminous point, placed at a far distance from the eye, through a convex lens of high dioptric value. Among some of the simple entoptic phenomena which may be cited are the following:—

(1) On winking the eyes transverse striæ are produced due, prob-

ably, to wrinkles of the epithelial layer. If this is continued for some length of time, as may be the case after reading for a long time in a horizontal position, striæ which last for several hours are produced and give rise to a marked diplopia of horizontal lines. This condition has been called *tarsal asthenopia.* The striæ produced by winking (after the drawing by George Bull) are shown in Fig. 75.

Fig. 75.—Entoptic Striæ Produced by Winking the Eyelids. (After George Bull.)

(2) The luminous spot is always limited by the shadow of the border of the iris: the irregularities of the latter can, therefore, be studied. The pupillary contraction is very readily seen on opening or closing the other eye.

(3) Small circles with bright centers are frequently seen and these

Fig. 76.—Speckled Appearance of the Entoptic Field Produced by Rubbing the Cornea. (After George Bull.)

have an apparent motion after an excursion of the eyelid; they are due to small specks on the anterior surface of the cornea and actually move in a direction contrary to their apparent motion.

(4) On closing and then opening the eyelids, after looking at a distant luminous point, long striæ running vertically are often seen. They are produced by the layer of tears in the conjunctival sac and

which assume near the borders of the eyelids a prismatic form with an outer concave and inner convex surface. Because of this shape of the tear-prism we have a prism of varying power and hence striæ rather than doubled images are produced.

(5) A rubbing of an eye causes the luminous spot to become

Fig. 77.—Star Figure of the Crystalline Lens. (After Helmholtz.)

speckled or mottled, due to the slight irregularities of the cornea or the irregular laying down of tear fluid. This soon disappears. Fig. 76 (after G. Bull) shows the speckled appearance of the entoptic field produced by rubbing the cornea.

(6) The star figure of the crystalline lens can frequently be seen.

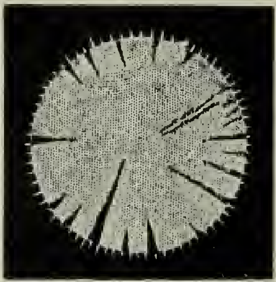


Fig. 78.—Incipient Cataract Seen Entoptically. (After Darier.)

A drawing by Helmholtz is shown in Fig. 77. This star figure is sometimes bright and sometimes dark with more luminous borders. Crystalline opacities are outlined with great distinctness. Hence many persons having such conditions can diagram and follow the development of the cataract step by step. Fig. 78 (after Darier) shows an incipient cataract as seen entoptically.

(7) Objects situated in the vitreous are easily seen: they become

partly visible by simply looking at the sky or when reading or working over a smooth white surface. This is particularly true when these objects are near the retina. The name *"muscæ volitantes"* has been given to this phenomenon. If the particle is in motion its direction can be determined by looking at the sky through a window upon

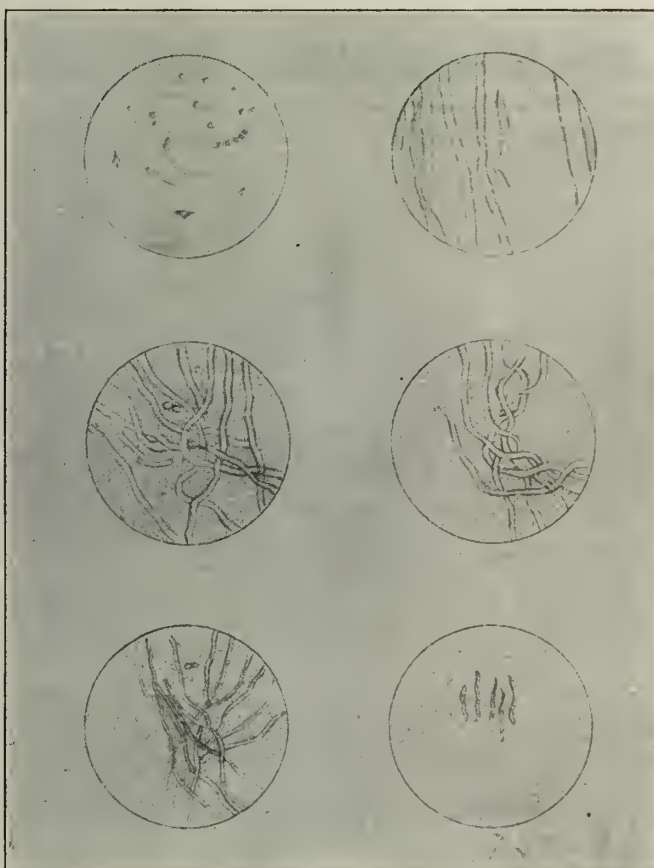


Fig. 78.—(A) Entoptic Figures. (After Bourdon-Cooper.)

which a point is taken to assure fixation and noticing whether the particle ascends or descends; the actual motion will be contrary to the apparent by virtue of the laws of projection of retinal images in space. J. Bourdon-Cooper (*Ophthalmic Review,* December, 1908) found that muscæ volitantes can be satisfactorily studied in the field obtained by using a low power objective in a microscope and placing

a high power objective upside down on the top of the eyepiece. With the usual condenser and diaphragm the field illumination can be regulated to give the greatest distinctness of the shadows. A simpler but very serviceable device can be made by fusing the end of a capillary glass tube until it forms a small glass sphere of which all but the sphere can be blackened to avoid light reflections. Studying entoptic phenomena by this means it is found that the string of beads commonly regarded as fixed in the vitreous have a movement which Bourdon-Cooper regards as an argument for a lymph space existing between the retina and the hyaloid membrane.

(8) Looking toward the sky bright points are frequently seen which move rapidly and then disappear giving rise, in turn, to others (Purkinje). Cobalt glass often aids in their observation. This phenomenon is explained as due to the pressure which is exerted on the sensitive layer by a globule of blood which is stopped in a narrow capillary.

(9) By compression of the eyeball for some time we can see the retinal vessels and notice the blood globules magnified about 50 times. The retinal vessels appear bluish. Before perceiving them, however, those of the chorio-capillary membrane, red on a black background, will be observed (Vierordt, Laiblin).

(10) On making, in a darkened room, rapid movements with the eyes we observe two luminous circles corresponding to the places of entrance of the optic nerves. These are due to the traction produced by the nerves during the movement.

(11) When making an effort of accommodation in a darkened room, ofttimes a very large luminous circle is seen. This is attributed to the traction which the ciliary muscle exerts on the interior membranes of the eye during the act of accommodation (Czermak).

(12) By looking towards the sky through a Nicol prism we see the brushes of Haidinger. This is in the form of an indistinct cross. One of the arms is yellow and the other blue. The phenomenon rotates in unison with a turning of the Nicol.

(13) If pressure is applied to a small portion of the sclera there is produced a phosphene corresponding to the inflection of the retina. This experiment, when performed in the dark, exhibits a feebly luminous disc surrounded by a bright border. Young was able to produce a phosphene corresponding to the macula in eyes which were rather prominent. External objects in the position of the phosphene were still visible but with pronounced deformities. By exerting a sufficiently strong and uniform pressure on the eyeball, the entire field will be darkened in consequence of the anemia of the retina. Ohle-

mann (*Ann. of Oph.*, 1909) gives a case of exophthalmic goitre in which the patient perceived a circular phosphene, like a radiating corona, ascribed to mechanical irritation of the retina. It was, without doubt, a pressure effect for it was seen at night at the height of the disease when the tension was the greatest.

(14) Looking at the sky through a narrow slit, the granulated ground and fine vessels which surround the macula will be distinctly seen, but the stenopaic opening must be kept in continuous motion for otherwise the phenomenon disappears. No results will be obtained by looking at the sky without the slit because the shadow of the vessel is too short to reach the sensitive layer. Similar phenomena are frequently observed when working with a microscope; if the field is illuminated with daylight the vessels can be seen by placing the eye at the ocular and giving it a to-and-fro movement.

(15) By observing a bright streak or line through a prism Maxwell observed a dark spot, corresponding to the fovea, which rose and fell with the direction of observation when this was confined to the blue portion of the spectrum but which disappeared immediately when the visual regard wandered from the blue. This is known as the *spot of Maxwell.* One can see this dark spot after having fixed the attention upon a yellow colored paper for a little time and then turning to a blue paper, or by observing the sky through a blue colored glass. The greenish-blue wave lengths (of the order of 5100 to 5200 Angstroms) are in the region for which the sensibility of the fovea is very inferior to what it is for the remainder of the spectrum. It might be possible to explain this phenomenon on the basis of the absorption of these radiations by the yellow pigment of the macula if the existence of this pigment in the living eye were definitely proven.

(16) Entoptic phenomena give a means of studying very *slight displacements of the eye* as a whole. For such experimentation Tscherning invented a small instrument known as the *entoptoscope.* It is shown in Fig. 79. It consists of a plate of wood (a) which is held between the teeth; on the vertical rod (b) is a spherical cup (c) pierced in the center by a small ($\frac{1}{10}$ mm.) opening which is to be on a level with the eye. At (d) are stretched two threads, one vertically and the other horizontally. When the instrument is adjusted and the observer looks toward the sky he sees the entoptic field occupied by the cross which is greatly enlarged. A point in the cross is selected for fixation. The position of the cross is thus dependent on that of the head. If then a displacement of the cross in the entoptic field is produced it is because the eye suffers displacement. It can be shown by this method that the eye is slightly displaced upward when we

wink the eyelids and a little downward when we open the eye very widely. When the head is tilted to one side the eye undergoes a slight displacement in the direction of the weight. These phenomena are more pronounced with the eye under eserine since the field is then very much smaller.

120. *Analysis of entoptic phenomena.* 1. *Observation of their parallax.* Upon fixing various points in the entoptic field or observing some of the phenomena which have been rehearsed above, the

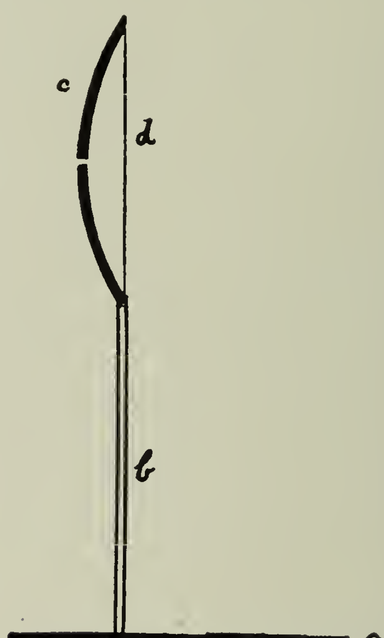


Fig. 79.—Tscherning's Entoptoscope.

entoptic phenomena are displaced in the field. If the particle which gives rise to the shadow is behind the pupillary plane, the shadow will move in the same direction as the visual line. This is shown in Fig. 80 in which *a* represents the pupil, *b* the particle and *V. L.* the visual line. In Fig. 80 (A) is represented a certain condition of visual line, particle and shadow. Suppose now that the eye is directed upwards. The visual line is directed upwards and the shadow, Fig. 80 (B) has descended to the lower portions of the retina. By the law of projection, however, the shadow will appear to have descended or the shadow moves in the same direction as the visual line. The contrary parallax

occurs if the object is in front of the pupillary plane and disappears if the object is in this plane.

2. *Measurement of the distances of the corpuscles from the retina.* Brewster proposed the use of two luminous points, as A and B in

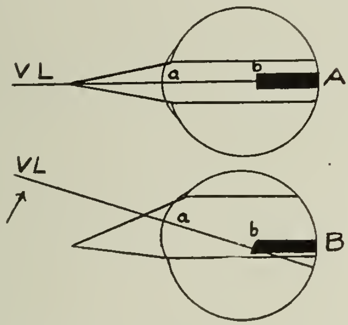
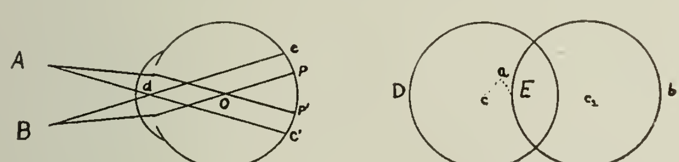


Fig. 80.—Parallax of the Entoptic Phenomena.

Fig. 81, of 0.1 mm. diameter and 2.5 to 3 mms. from each other. These points must be in the anterior focal plane of the eye in order to give parallel light within the eye. Let d be the middle of the pupil and O the object (or particle). Then p and p_1 will be the shadows cast by O and c and c_1 the centers of the circles of diffusion since d represents the central point of the pupil. Also from the diagram, dc and op are



Figs. 81-82.—Determination of the Position of an Entoptic Object. (After Brewster.)

parallel; likewise dc_1 and op_1 are parallel. Hence from the triangles dcc_1 and opp_1 we have the ratio

$$\frac{pp_1}{cc_1} = \frac{op}{dc}$$

Two circles of diffusion are seen which partly overlap. We measure the distance pp_1 between the two shadows of the same object and the diameter, DE, of the free part of one of the diffusion circles as in Fig. 82. The ratio between these measurements is equal to the ratio

between the distances of the object from the retina and that of the retina from the pupil. Fig. 82 shows that $ec_1 = DE = R + a$, if R is the radius of the circle of diffusion. One has, therefore, only to project the mutual distance of the two centers, i. e., the breadth of the uncovered part of the circles and that of the double shadows of any object in order to obtain the experimental data necessary to solve the equality of ratios given above and determine *op*, the distance of the particle from the retina. For more complete details and description of Brewster's method the reader is referred to the volume on the *Accommodation and Refraction of the Eye*, by Donders. The measurement of the projected images is most readily effected by the method *à double vue* due to Doncan; looking through the two small openings downwards on a mirror reflecting the light we can with the other

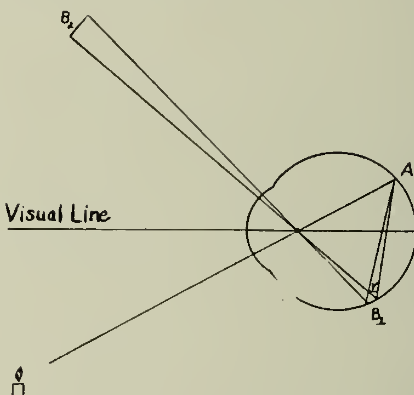


Fig. 83.—Entoptic Observation of the Vessels. (After H. Müller.)

eye project and measure the forms on an adjoining sheet of white paper. Taking into account the distance at which we project, the magnitudes of the retinal shadows are readily obtained.

121. *Entoptic observation of the vessels of the retina.* The retinal vessels, greatly magnified, may be seen projected into the dark portions of a room if, in a dark room, a candle is held at some distance from the eye and the gaze is directed straightforward. The retinal vessels appear of a dark bluish color on a semi-luminous orange background. If we move the candle toward or away from the visual line the vessels are apparently displaced in the same direction. The fovea is without vessels; in some eyes it has a star-like appearance and in others it appears as a luminous disc.

Henry Müller explained these phenomena. In Fig. 83 there is formed at A a retinal image of the candle. This portion of the retina

thus illuminated sends diffuse light in all directions. A retinal vessel at r, for example, intercepts the rays Ar so as to form a shadow B_1 on the sensitive layer of the retina. This is the shadow which is ultimately seen; it will be appreciated that the shadow B_1 and the vessel r are actually very near together. The shadow at B_1 is seen projected in space as B_2. It can also be seen from the figure that a movement of the light source toward the visual axis will cause a movement of the retinal vessels in the same direction. Direct illumination also produces these images of the vessels on the sensitive part situated behind it, but the shadow is rarely perceived under these conditions probably because this shadow is always formed at the same place in direct fixation and the retinal layer has thus become accustomed to this as a normal procedure.

Light may be concentrated on the sclera by means of a convex lens, as shown in Fig. 84, as near the sclero-corneal border as possible. The

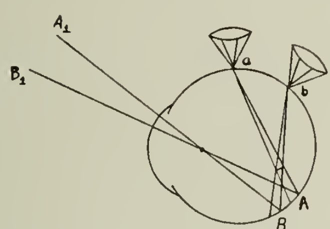


Fig. 84.—Entoptic Observation of the Vessels by Illumination of the Sclera.

dark vessels on an orange background can be seen. The vessels move in the same direction as the luminous focus as shown by their projections in Fig. 84. The explanation is the same as given in connection with Fig. 83; the light of the image of the flame formed on the sclera passes through this membrane and the choroid and causes shadows of retinal vessels. H. Müller measured the distance ab of the displacement of the focus of light on the sclera and the displacement AB of the shadow of a vessel corresponding to this displacement of the light source. Necessarily the distance between the projected images A_1 and B_1 and the distance from the point A_1 or B_1 to the nodal point of the eye must be known in order to calculate the size of AB. Müller calculated that the vessel should be 0.17 mm. to 0.33 mm. in front of the sensitive layer. This experimentation seems to prove that it is the layer of rods and cones that is the sensitive layer, for the distance of the small vessels near the macula from the layer with the cones is about 0.2 to 0.3 mm.

Letters are sometimes seen vividly colored in red when reading in

strong sunlight. This may be explained as due to the component of the sunlight, namely the red, which is transmitted through the membranes of the eye. This would be added to the light coming through the pupil. The red would be too feeble to affect the white tint of the paper but would tinge with red the black letters which reflect to the eye practically no light.

If one eye is illuminated while the other is in the shade it will be found after a little that, on alternately closing the eyes, a white object appears greenish to the illuminated eye while it appears reddish to the other eye. The explanation lies in the fact that the light which passes through the membranes of the outer eye is colored red by the vessels of the choroid coat. This red light fatigues the retina of the illuminated eye and this has the effect of making a white object appear greenish in color; the other eye sees it red by contrast.

Both these phenomena may be readily observed in the refracting room and may indeed be sources of annoyance as well as of error unless the presence of brilliant luminous sources, such as incandescent lamps, near the patient's head or in his direct field of view is guarded against. A uniform illumination, such as is obtainable by the present indirect or semi-indirect lighting systems, will afford relief from some of these entoptic phenomena which may arise from no other cause than the presence of side-lights or the promiscuous distribution of luminous sources in refracting rooms and which may have thereby aroused a suspicion of pathologic conditions (or changes which may be associated with such disturbances in color-vision) as would occur to a practitioner when a patient says: "The letters are equally readable with each eye, but they appear sort of reddish with my left (or right) but all right with my other eye." Cases of this kind have arisen in practice which have been found to be uniformly correct and normal in each eye (i. e., letters black and backgrounds white) when the room was flooded with subdued sunlight.

122. *Diffraction in the eye.* If an observer looks at a very brilliant light source he will observe the phenomena of diffraction due to the non-homogeneity of the ocular media. These phenomena are very striking and are designated by the name of "ciliary coronæ." This ciliary corona is composed of an infinity of very fine, many-colored radiations which cross through the whole of the luminous area. Its extent depends upon the intensity of the light source. With an arc lamp or the image of the sun reflected from a convex mirror there will be obtained a diameter of the corona which may reach 8 degrees or more. In addition to the ciliary corona most people see around

the entire luminous source a vivid diffraction ring, which we shall specify as ring *A*, presenting the colors in the order red to blue from the outside toward the center. This ring is separated or distant from the light by a diameter of about 3 degrees for the blue. If the luminous source is not very bright this ring forms the limit of the corona, but if the intensity is high the diameter of the corona may attain a value double that of the ring. The phenomenon appears to be a universal one. Anyone walking along a street lighted by gas or electric lamps may readily observe the phenomena and will be interested to see the manner in which the appearance of the corona and diffraction ring depend upon the proximity to the light source. Viewing a luminous source from some distance when passing along a darkened street one will often see two diffraction rings both of which are fairly faint. Upon closer approach the inner ring becomes more luminous while the outer one disappears. These phenomena will be referred to in the succeeding paragraphs; suffice it to say that the pupil is dilated when in the dark and contracts as one approaches the luminous source.

123. Druault (*Compte rendu du Congrés d'Ophthalmologie d'Utrecht*, 1899) describes the second diffraction ring, designated as *B*, which is seen when the eye is dilated with cocaine, in addition to ring *A*. It presents the colors in the same order as ring *A* but is more irregular and composed of radial striæ. The blue border of the outer ring seems to be superposed on the red portion of the inner ring. An examination of these phenomena using monochromatic light causes some minor changes in their character. For under these latter conditions the ciliary corona presents the form of a luminous dust within which one sees some radial striæ. Quite near the luminous source are one or two very fine black rings due to the diffraction by the border of the pupil. That portion of the luminous "dust" or haze close to the luminous source appears to have a constant motion of the nature of contractions and dilatations which probably correspond to changes of the pupil. The ring *A* exhibits itself as a concentration, regular and circular in form, of the luminous dust. Using yellow light the diameter of this ring is about 4.5 degrees. If one covers a portion of the pupil, all portions of ring *A* disappear at once. The ring *B*, of about 7 degrees diameter, presents the same irregular and striated appearance with yellow light as with white. If one covers a part of the pupillary area the corresponding portion of the ring *B* disappears and the other half becomes much more regular. It is probable that the ring *A* is due to the epithelial cells of the cornea and is of the same nature as those which can be seen by looking

through a plate glass covered with lycopodium. We can calculate the diameter D of the particles causing the phenomenon from the formula

$$D = \frac{2k\lambda}{\sin a}$$

in which λ signifies the wave length and a indicates the angle of deviation or one-half of the angular diameter of the ring and k a constant which, for the first ring, has a value of 0.819. When $a = 2° \ 12'$ and $\lambda = 5900$ Angstroms, D has a value of 25 μ. Schioetz measured the dimensions of the superficial cells of the epithelium of the cornea and found sizes varying from 25 μ to 40 μ. He likewise showed that on exposing the cornea to the action of distilled water for some time one observes a system of rings of which the first corresponds practically to the ring A; it is a little smaller however. Druault, on the other hand, on looking through a dead cornea found a ring the dimensions of which differed but little from those of ring A and which was undoubtedly due to the endothelium of Descemet's membrane, for he could remove the entire epithelium of the anterior corneal surface without producing any effect, but the ring disappeared as soon as the endothelial layer was touched. The ring B, on the other hand, is doubtless due to the crystalline fibers which are arranged in the form of a network or grating. The size of the openings or slits between these fibers can be calculated from the formula

$$a = \frac{\lambda}{\sin b}$$

which gives for $\lambda = 5900$ Angstroms the value $a = \dfrac{0.59\ \mu}{\sin 3° \ 33'} =$ 9.5 μ. This corresponds closely to the size of the crystalline fibers (10 to 12 μ). The ciliary corona is probably, like the ring B, a phenomenon due to meshes or, in other words, is to be attributed to the structure of the crystalline. With feeble luminous sources and dead crystalline lenses suspended in air one can observe phenomena closely resembling the corona.

124. Glaucomatous patients usually see rings which resemble those just described but they are generally larger and of about 10 to 12 degrees angular diameter. The size of the rings increases as the distance between the corpuscles or cells producing them decreases.

Schioetz attributes the origin of the glaucomatous rings to the deepest layer of the corneal epithelium, the cells of which are much smaller than the superficial ones. Experiments on pigs' corneæ, so arranged that salt water could be forced into them, showed that a large circle of diffraction was produced at the time that the liquid penetrated between the deeper epithelial cells. Rings are also often seen by persons suffering with conjunctivitis and are analogous to those which can be produced by the introduction of a drop of blood in the conjunctival sac. A prominent ring of diameter 7.5 degrees for yellow is found, surrounded by a second paler ring. The space between these rings is not black, however, as in the preceding cases but is yellowish to maroon in color.

XII. THE MECHANISM OF ACCOMMODATION

125. In emmetropia the macula lutea coincides with the posterior focal plane of the eye and such an eye, if otherwise normal, will receive a clear image of a distant object. An image of a near object would be formed at its conjugate focus but behind the posterior focal plane. The light would thus be intercepted by the retina before reaching this conjugate focal plane, forming upon the retina diffusion circles. The image of the object, being an aggregation of such diffusion circles, would be blurred. In order to prevent this indistinctness of vision the power of accommodation must be exercised. This is a dynamic function and is called into play by an eye whenever it fixes an object within its far point. The various refractive conditions of the eye and their near and far points, together with their amplitudes of accommodation have been discussed at some length under the portion of this monograph devoted to *Refractive anomalies.*

Five theories have been advanced to account for the manner in which the eye accommodates: (a) increase of curvature of the cornea, (b) increase of curvature of the crystalline lens, (c) elongation of the globe, (d) advance of the crystalline lens and (e) contraction of the pupil. These last two can be readily disposed of, for it can be easily seen that, if the crystalline lens could advance so as to touch the cornea, this would not be sufficient to account for any considerable amplitude of accommodation. The accommodative contraction of the pupil, discovered by Scheiner, is not sufficient to explain accommodation. The theory of the change of curvature of the cornea was supported by the measurements of Home and Ramsden made toward the end of the eighteenth century. This hypothesis and the discussion which arose in connection with it resulted in the very valuable researches of Sturm and of Arlt. The investigations of Sturm on the

form of the astigmatic pencil were undertaken to show that accommodation did not exist but that near and distant points were seen with the anterior and posterior parts respectively of the focal interval. When Arlt discovered that myopia depended in general upon an elongation of the eyeball, he labored under erroneous ideas as to accommodation for he thought that an elongation of the globe was brought about by the action of the external muscle when a near object was viewed. By making autopsies on some excessively myopic eyes he was able to prove a lengthening of the globe and believed that he had confirmed his hypothesis. The hypothesis was, in the end, of no value but his experimental demonstrations of the connection between elongated globes and myopia were of the greatest value.

126. *Researches of Young.* The first definite proof that accommodation is due to an increase of convexity of the crystalline lens was given by Young. This great savant wrote his treatise on the *Mechanism of the Eye* (*Philosophical Transactions*) in 1801. He eliminated possible corneal curvature changes during accommodation by observing that during this act there was no change in corneal images but that an easily visible change could be produced by exerting a pressure on a peripheral part of the cornea; this change of curvature was considerably less than that which would be necessary to explain accommodation. But Young added further to the evidence on this subject by his classic experiment of "putting the eye under water." This he did by taking the objective of a microscope which had as nearly as possible the same refractive power as the cornea, filling the tube with water and placing it in front of his eye also submerged in water. The cornea was thus surrounded on both sides by the same liquid practically and was thus eliminated and replaced by that of the unchangeable objective. In this experiment the amplitude of accommodation (about 10 diopters for Young) was preserved, proving that it was not a function of the cornea. To show that accommodation is not produced by an elongation of the globe Young devised the scheme of turning his eye inward as far as possible and applying to its anterior surface a strong metal ring. He then applied the ring of a small key to the exterior side between the eye and the bone until the phosphene, produced by pressure, reached the fovea. The rings were maintained fixedly in place; the eye thus pinned down could not lengthen. He found that accommodation was not abolished and that the phosphene, which would have extended over a great area due to pressure if elongation should have resulted, did not change its size. By using his optometer Young proved that persons operated on for cataract lost their accommodative powers. He thus firmly established

his belief that this power resides in the crystalline lens and hence that it could only result from an increase in the curvature. Young knew nothing about the nature of the ciliary muscle and its contractility, however, and was unable to formulate a theory to explain the mechanism of accommodation.

127. *Researches of Langenbeck, Cramer and of Helmholtz.* The fact that accommodation is accomplished by an increase of curvature of the crystalline lens was first objectively demonstrated by Langenbeck

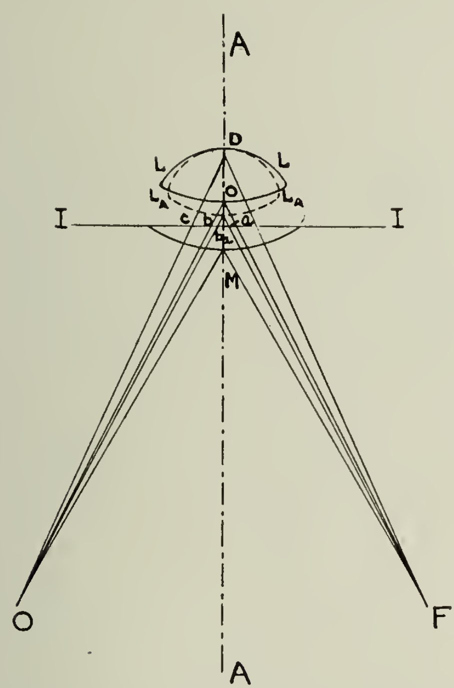


Fig. 85.—Diagram Showing How Reflected Images are Formed. Illustrative of the classic experiments of Cramer and Helmholtz.

in 1849. He observed the changes in the images formed by reflection at the anterior surface of the lens. The images of Purkinje, discussed in the paragraphs devoted to the *Catoptrics of the eye,* were examined and an increase of curvature of the anterior surface of the crystalline lens observed. In 1851 Cramer constructed a magnifying instrument, which he called an *ophthalmoscope,* with which he was able to demonstrate clearly the movement of the images which occurred during accommodation, proving that the anterior crystalline surface made a quite extended centripetal movement. This centripetal movement

has been erroneously interpreted at different times by various experimenters to indicate a see-saw movement of the crystalline lens. It is probable, however, that there is a slight trembling or shaking of the lens in the act of accommodation. Fig. 85 attempts to diagram schematically the positions of the three Purkinje images seen during repose and during accommodation when the eye is illuminated by a light source at F and observations of the phenomena are made with the observer at O, the line of the subject's vision being AA. It is to be noted that refractive changes influencing the directions of rays are neglected in Fig. 85; this is to simplify and to present the essential points involved in the classic experiments of Cramer and of Helmholtz. M represents the anterior corneal surface, II represents the plane upon which are seen the reflected images, LL and L_AL_A the crystalline positions of repose and of accommodation respectively. The ray FM, by reflection to O, gives the anterior corneal image at a. The ray FD, neglecting refraction as previously explained, after reflection at the posterior surface of the lens, gives the image due to reflection from the concave posterior lenticular surface at c. With the lens in a position of repose the anterior lenticular image is at b, but upon accommodating the image is found at b_a as can be seen by following the course of the dotted lines in Fig. 85. This indicates a centripetal movement and shows that the accommodative change takes place in the anterior crystalline surface. Cramer attributed this change, however, to the contraction of the iris: he believed that the iris was, in a state of repose, in a swollen condition and that it flattened during accommodation, thus exerting a pressure on the peripheral parts of the crystalline lens and that the ciliary, contracting simultaneously, exerted a traction on the choroid pushing the vitreous forward, thus subjecting the crystalline to a pressure except on the pupillary part. These ideas had to be abandoned when v. Graefe published his case of complete aniridia in which the amplitude of accommodation was intact, thus limiting the active agent in accommodation to the ciliary.

128. At the same time, and independently of Langenbeck and of Cramer, Helmholtz found the same results but added that the posterior surface of the crystalline is also modified though but slightly. He finally invented his ophthalmometer by means of which observations of the forms and variations in forms of the various surfaces of the eye have been rendered so precise. Helmholtz used two sources of light, a lamp and its image by reflection from a mirror. His results are pictured in Fig. 86. In these diagrams A represents the condition of affairs with the eye in a state of repose, and B that of accommodation; a, the corneal reflexes; b, reflexes from the anterior surface of

the crystalline, smaller and consequently nearer each other during accommodation (*B*) and nearer to those from the cornea; *c*, reflexes from the posterior surface of the crystalline lens, least luminous of all, keeping their positions and becoming slightly smaller during accommodation. It is now universally agreed that the accommodation of the eye is produced by a change in the form of the crystalline lens, by virtue of which the anterior surface of this lens advances and becomes more convex while the posterior surface increases but little in convexity and changes its position but slightly if at all. From his investigations Helmholtz adopted certain values for his schematic eye and these have been quite generally accepted. These numbers, together with his results upon the dead eye, are tabulated below.

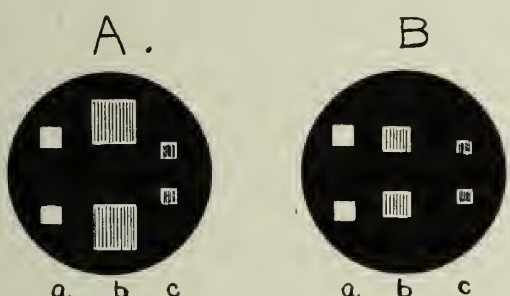


Fig. 86.—Purkinje Images During Repose and Accommodation.

A, state of repose. B, state of accommodation. *a*, corneal reflexes; *b*, reflexes from anterior surface of crystalline; *c*, reflexes from the posterior surface of the crystalline lens.

	Schematic		*Dead Eye*	
	Repose	Acc.	A	B
Radius of anterior surface...	10 mm.	6	10.16	8.87
Radius of posterior surface..	6 mm.	5.5	5.86	5.89
Thickness	3.6 mm.	4	4.2	4.31
Focal distance	43.71	33.79	45.14	47.44
Total index of refraction....	1.4545		1.4519	1.4414

129. The ciliary muscle is the agent by or through which the lens becomes more convex during accommodation. It is still a question whether the zonula is relaxed or is tense during accommodation and there are different views which are held as to the exact form the lens assumes during the act of accommodation. The two chief theories are due to Helmholtz and Tschering; some of the essential points of difference with supporting proofs will be outlined in succeeding paragraphs. The reader is referred to the masterly writings of these

men for details. The anatomical facts which may with propriety be succinctly stated here relative to the ciliary region are as follows: The lens, enclosed in its capsule, is supported between the aqueous and the vitreous by a delicate ligament, the *zonula of Zinn* (or the suspensory ligament). This ligament is attached to both surfaces of the capsule near the peripheral border of the lens. The ligament thus attached to the lens has its outer border attached to the ciliary processes and the depressions between them. The ciliary processes are a network of blood vessels and pigment which line the inner circumference of the sclero-corneal ring and which, running backward, become united with the choroid. The muscular nature of the ciliary was discovered by Wallace, an American physician, in 1836; the credit is usually given to Bowman and Bruecke (1846).

The ciliary muscle lies beneath the ciliary processes, is composed of non-striated fibers and is made up of two parts. One portion consists of longitudinal or meridianal fibers which are attached anteriorly to the sclera near the canal of Schlemm and passing backward are inserted in the anterior portion of the choroid. The outer surface of the muscle is in contact with the sclera. On the inner side of the meridianal fibers are the transverse or circular fibers ordinarily known as the annular muscle of Mueller. This consists of a circular band of fibers surrounding the margin of the iris. Some of the fibers, after proceeding for a certain distance transversely, penetrate this portion of the muscle and join the meridianal part.

130. *Statement of the theories of Helmholtz and of Tscherning.* Helmholtz first presented a rational explanation of the way in which accommodative changes are accomplished. He believed that in a state of repose the crystalline lens is kept flattened by a traction exerted by the zonula. A contraction of the ciliary muscle, of which the anterior extremity is attached to the firm sclero-corneal border, would then draw forward the anterior portion of the choroid, to which the posterior extremity is attached, during accommodation. As a consequence of this forward motion the ciliary processes and the suspensory ligament of the lens would also be drawn forward and a relaxation of the zonula would occur. The crystalline lens would then swell by its own elasticity, approaching the spherical form.

On the other hand, according to the views which have been recently elaborated by Tscherning and his collaborators at the Sorbonne, it is considered that when the eye is adjusted for distance it is entirely at rest. The ciliary muscle is relaxed, the zonula is also relaxed and the convexity of the lens is just sufficient under conditions which are normal, to produce a clear image upon the retina. When, however,

accommodation is effected, the contraction of the ciliary muscle produces a tension of the zonula and this is of such a character as to cause an increase in the convexity of the anterior surface of the lens or, as Tscherning calls it, a temporary "*anterior lenticonus.*"

Helmholtz confined his measurements to the portions of the surface near the optic axis. Tscherning has carried on numerous researches involving measurements of curvatures of more peripheral parts of the lens surface. Briefly stated, he has found that the curvature of the anterior surface, which is chiefly instrumental in accommodation, diminishes very rapidly as the distance from the axis increases, and concludes that the anterior surface of the lens assumes in accommodation a form closely approximating an hyperboloid.

131. *Helmholtz theory—Observations and experiments in support thereof.* The first experimental observations undertaken to test the correctness of the assumptions of Helmholtz were by Hensen and Voelkers (*Arch. für Ophthal.*, 1873) performed upon the lower animals. They thrust very fine needles into the eye a little behind the ora serrata; on stimulating the ciliary ganglion they saw the free extremity of the needle describe a movement backward. They were able to demonstrate:—(1) a contraction of the pupil with a forward motion of the pupillary border of the iris and of the anterior surface of the lens with an increase of curvature of this latter surface and (2) contraction of the ciliary muscles with advancement of the ciliary processes and anterior portion of the choroid.

132. Coccius (1867) and Hjort (1876) observed the changes which occur in the living eye during accommodation; the first named experimenter observed eyes upon which peripheral iridectomies had been performed, while the latter made use of a person in whom there existed total aniridia, due to accident, but who possessed an accommodation of 5.8 D. The changes which these investigators observed were analogous to those described by Hensen and Voelkers. They were also able to view the ciliary region directly and to demonstrate that the ciliary processes advance during accommodation. In recent years Hess has conducted experiments in which he concludes:—(1) that the suspensory ligament is in a relaxed condition during accommodation because he succeeded in demonstrating that the observations of Coccius and Hjort are correct, (2) a sinking of the lens from gravity when the eye makes a maximum effort of accommodation and (3) a change of position of the lens during accommodation with change of position of the head; that is, a forward movement when the head is inclined forward and so forth. The experiments of Hess are given in detail in the *Transactions of the A. M. A. Ophthalmological Section*, 1907.

133. A considerable amount of discussion has ensued over the measurements of the thicknesses and curvatures of surfaces of dead and living eyes as made by Helmholtz. Helmholtz measured the thickness of the crystalline lens and found it a little greater during accommodation than in a state of repose; he also measured two dead crystalline lenses and found their thicknesses greater than those of living eyes in a state of repose. This may depend on elongation of the lens through tension of the zonula of Zinn during life as a result of the pressure of the vitreous humor, while after death, when the pressure ceases, the tension may diminish and the lens consequently become thicker. Tscherning doubts whether these autopsies tell in favor of the theory of Helmholtz because (1) measurements of the thickness of a living lens are not within the limits of error experimentally; "the much disputed question of knowing whether the crystalline lens changes its thickness during accommodation can with difficulty be decided by the observation of the crystalline images, for the alleged change (an increase of 0.4 mm.) does not exceed the limit of error" (Tscherning) and (2) dead crystalline lenses do not possess the accommodative form but the radii of curvature are those corresponding to the living eye in a state of repose. Helmholtz's measurements of the radii of curvature of the anterior surfaces of three living eyes in a state of repose were 11.9 mm., 8.8 mm. and 10.4 mm., while for the dead eyes he found 10.16 and 8.87 mms. Stadfeldt, in 1896, measured eleven living human crystalline lenses in repose obtaining with the ophthalmometer an average radius of curvature of 10.6 mms. for the anterior surface of the crystalline. The average with a half-dozen dead crystallines taken from the eyes and measured with a Javal ophthalmometer without any traction being applied was 11.4 mms. Souter, in his textbook on the *Refractive and Motor Mechanism of the Eye* reports some investigations made upon the healthy lens of a man twenty-five years of age immediately after the enucleation of the eye. Upon removal of the lens from the eye he observed that the usual flattened aspect of the anterior surface was absent and resembled very closely the accommodative form described by Tscherning. Traction made at opposite points of the equator of the lens produced a decided flattening of curvature which disappeared on release from traction: "the action of the lens did not in any way justify a belief in Tscherning's theory."

134. If we assume with Helmholtz that there is a relaxation of the suspensory ligament as a consequence of the forward motion of the ciliary processes and the zonula, we need only to glance at Fig. 87 and recollect the nature of the constitution of the crystalline lens in order

to see what will be, in a general way, the effect of such a relaxation upon the shape and position of the lens. The crystalline lens and ciliary region during repose and when in a state of tension are represented by heavy lines; the dotted outline represents the changes which occur during accommodation.

In childhood, when accommodation is most active, the lens consists of a gelatinous mass enclosed in a contractile capsule. Such a mass will assume a shape approximating the spherical form according to the physical law that a fixed volume of liquid presents its smallest area of external surface when in this form and the contractility of

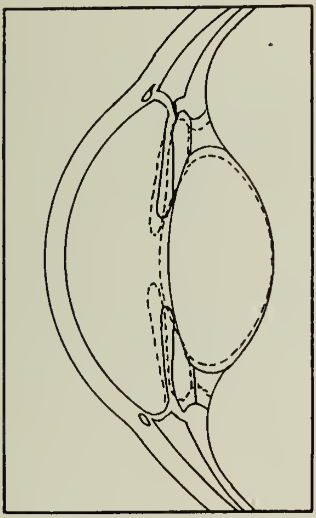


Fig. 87.—The Crystalline Lens and Ciliary Region.

The dotted outline represents the change which occurs in the act of accommodation according to Helmholtz.

the capsule is ever acting to reduce this surface area. A rubber bag filled with water illustrates this condition very well; by pressure or traction on the bag its shape is altered but its original form will be resumed by release from pressure or traction. In the case of the lens there are modifying conditions resulting from its characteristic structure which prevent its assuming a spherical shape even though all external pressure is removed. Again, the anterior portion of the suspensory ligament is shorter than the part attached to the posterior surface of the lens and as a result—presumably—the tension will be greater upon the anterior than upon the posterior surface of the lens; hence the effect of relaxation must be greater upon the anterior

crystalline surface, allowing this to advance with a decided increase in curvature. The posterior surface, on the other hand, will be but little affected either in curvature or position.

135. *Experiments of Tscherning and his collaborators. I. The overcorrection of spherical aberration during accommodation and the peripheral and central amplitude of accommodation.* Aberroscopic phenomena show that most persons see the shadow concave toward the periphery, but on effecting accommodation the forms of the shadows change: these shadows turn their concavity toward the middle or the center (see Fig. 57). The central refraction must, therefore, have increased more than the peripheral refraction. Fig. 61 (l. c.) exhibits a condition of overcorrection of the aberration, proving that the pupillary contraction cannot have been responsible for the effects. The optometer of Young affords a means of measuring directly the difference between the central and peripheral amplitudes of accommodation. The central accommodation can be measured with the two narrow and closely situated slits placed near the pupillary center and the peripheral accommodation with the triangular plate lowered just enough to permit of seeing the two lines. Some measurements recorded by Tscherning (*Encyclopédie française d'Ophthalmologie*, Vol. III) are as follows:—

Subject	Central Amplitude (Interval = 0.75 mm.)	Peripheral Amplitude (Interval = 5 mms.)
Young	9.8 D.	4.2 D.
Koster	8.0 D.	3.3 D.
Demicheri	7.5 D.	3.7 D.
Mme. T.	6.7 D.	3.8 D.
Tscherning	3.0 D.	1.25 D.

136. The methods of skiascopy with a luminous point furnish an objective method of studying accommodative changes. A fixation stand is placed before the party under observation at a point very close to his punctum proximum; the observer throws the light from a well-screened lamp into the observed eye using a concave mirror which forms an image of the luminous point at about the same position as the point of fixation. To make the observation it is best to select, when possible, a person whose pupil is well dilated with cocain (since the accommodative power is not to be allayed) who is also emmetropic and who does not have too much aberration when the eye is in a state of repose. Skiascopically, then, when the person under observation

accommodates, the borders of the pupil will be illuminated and separated from the small bright luminous area in the center by a dark zone as shown in Fig. 88 (b). As long as the person does not accommodate the whole pupil will be entirely illuminated. Fig. 88 (a) shows by contrast with diagram (*b*) the appearance in a non-accommodated eye made myopic by a convex lens. The degree of aberration can be determined from skiascopic observations by measuring the distance from observer to observed. For example, if the fixation point is placed at 10 cms. (10 D.) from the observed eye and if the operator when at 50 cms. (2 D.) sees the ring there is an aberration of 8 diopters. By approaching closer and closer to the point of fixation the ring becomes thinner and thinner but it is rare that it disappears entirely before the accommodation attains a high degree.

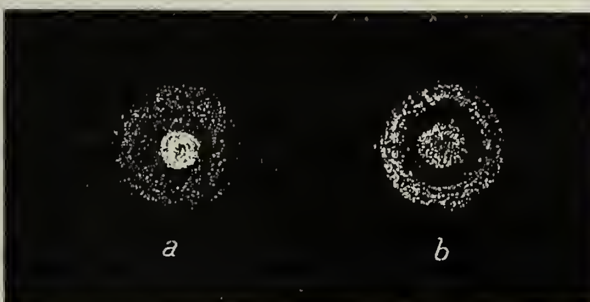


Fig. 88.—Skiascopic Examination of Accommodation.

a, appearance of the emmetropic eye made myopic with a lens of + 5 D. *b*, appearance of the same eye, accommodating 5 D., without lens. (After Tscherning.)

From these experiments Tscherning concludes that the amplitude of accommodation diminishes toward the periphery of the pupil.

137. *(II). Changes in the form of the crystalline surfaces during accommodation.* Tscherning and his pupils conducted a series of experiments with the ophthalmophakometer to determine the curvatures and thicknesses of the crystalline during repose and accommodation. They differ little in many essentials from the results of Helmholtz but do appear to indicate that the increased thickness of the crystalline when in the accommodated state is due to a recoil or retrogression of the posterior surface. It also appears that the crystalline undergoes slight displacements, forward or backward, at the same time it changes form, but the determinations of the positions of the surfaces cannot be made with sufficient accuracy to warrant any

definite conclusions. The dioptric power of each surface can be calculated from the relation

$$D = \frac{n - 1}{R} = \frac{1.074 - 1}{R}$$

The following table gives a representative set of data on an eye, (A) from the experimentation of Helmholtz and (B) from Tscherning. Table (C) gives the dioptric values of the changes during accommodation as taken from Tscherning's data.

Table A (Helmholtz)

	Repose	Accommodation
Radius of anterior surface................	11.9 mms.	8.6 mms.
Radius of posterior surface................	5.8	...
Depth of chamber (anterior)............	4.0	3.7
Thickness of lens........................	3.2	3.5
Position of posterior surface..............	7.2	7.2

Table B (Tscherning)

	Repose	Accommodation
Radius of anterior surface................	9.7 mms.	5.4 mms.
Radius of posterior surface................	5.7	5.3
Depth of anterior chamber................	3.6	3.5
Thickness of lens........................	4.0	4.3
Position of posterior surface..............	7.5	7.8

Table C

	Repose	Acc.	Diff.	Repose	Acc.	Diff.
Anterior surface	7.6D	13.7D	6.1D	6.5D	11.3D	4.8D
Posterior surface	13.0	14.0	1.0	13.2	16.5	3.3
Total diopters	20.6	27.1	7.1	19.7	27.8	8.1

These and similar results indicate that the rôle of the posterior surface of the crystalline is not negligible in accounting for accommodation.

138. Young believed that it was impossible to explain the negative spherical aberration of an eye other than by a flattening of the peripheral parts of the crystalline. Tscherning succeeded in giving a tangible form to this conception by using the arc of the ophthalmophakometer in a horizontal position carrying three lamps so situated as to permit of all three images formed by the anterior surface of the crystalline being visible in the pupil. The gaze of the observed party is so directed that the three images are situated near the upper border. In a state of repose these images are all in a straight line or else slightly concave toward the center; during accommodation they form a curve convex towards the middle, the curvature of which is greater in proportion as the accommodation is increased. Fig. 89 shows these effects and is taken from the work of Crzellitzer: diagram (1) is for an accommodation of one diopter, (2) for an accommodation of 5

diopters, (3) for an accommodation of 6.7 diopters and (4) shows the positions of the three images under an accommodation of 9.1 diopters. These phenomena indicate a greater curvature at the middle than at the periphery. This can be seen more readily by employing three other lamps on a similar cursor to that used in the above experimenta-

Fig. 89.—Images of the Anterior Surface of the Crystalline Lens. (After Crzellitzer.)

1, Accommodation of 1 D.; 2, Accommodation of 2 D.; 3, Accommodation of 6.7 D. and 4, Accommodation of 9.1 D.

tion and placed vertically above or below the first carrier. Let us assume the conditions represented in Fig. 90 and consider as objects the distances between the two lamps situated on the same vertical line. During repose there would be three images all of the same size represented by a_1, a_2 and a_3 in Fig. 90, showing that the curvature is every-

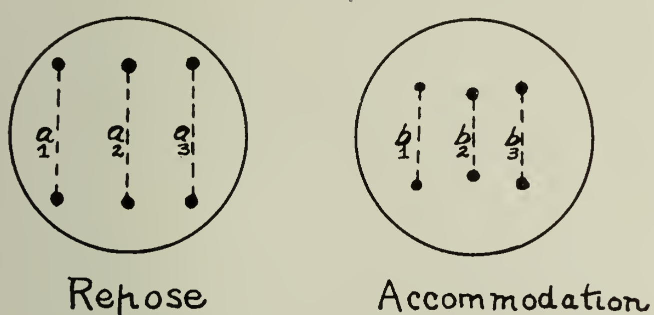


Fig. 90.—Diagrams Showing that the Curvature is Everywhere the Same During Repose, but that the Curvature Increases at the Center During Accommodation.

where practically the same. But during accommodation the middle image, b_2 of Fig. 90, is considerably smaller than the other two images, b_1 and b_3, showing that the curvature is greater.

139. The peripheral parts undergo a real flattening which causes, however, an increase of refraction; it might appear from the above considerations as though the curvature of the peripheral parts in-

creased during accommodation but not as rapidly as at the center. It is to be remembered that, except at the axis, it is the normal and not the radius of curvature which plays the part of the radius of the refracting sphere, assuming that the luminous point is on the axis. Tscherning gives a clear and mathematically elegant treatment of this subject and the method of applying his ophthalmophakometric observations in the *Encyclopédie française d'Ophthalmologie,* Volume III, pages 268-272. We shall quote his results later, but will include at this point a simple example illustrating the calculation of the radius of curvature, ρ, from the formula

$$\rho = \frac{N^3}{\rho_0{}^2}.$$

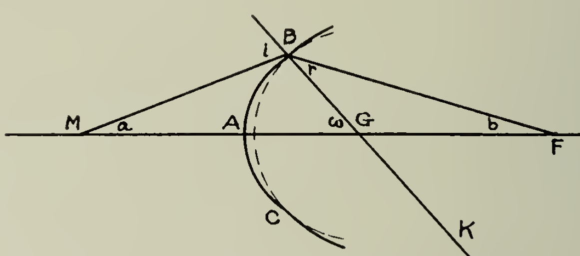


Fig. 91.—Refraction by a Parabolic Surface.

In Fig. 91 let BAC represent a curve of the second degree, MF its axis and BK the radius of curvature at the point B, BG the normal and the dotted curve, a circle, drawn with BG as radius. The luminous ray MB is refracted in the direction BF exactly as if the surface were replaced by a circle of radius BG. Assuming that the accommodation is accomplished solely by the anterior surface and taking the data previously given with regard to the accommodation of Demicheri, who had centrally an accommodation of 7.5 D. and at 2.5 mms. from the axis an accommodation of 3.7 D., let us suppose that 10 mms. represents the radius of the anterior surface in a state of repose and that 1.06 is the index of the crystalline relative to the aqueous humor. Then the refractive power centrally of the anterior surface is

$$D = \frac{n - 1}{r} = \frac{0.06}{0.010 \text{ meter}} = 6 \text{ Diopters}$$

During accommodation the central refraction increased 7.5 diopters.

giving a total refracting power of 13.5 diopters. The radius of curvature at the centre, ρ_c, can therefore be gotten from

$$\frac{n-1}{\rho_c} = \frac{0.06}{\rho_c} = 13.5 \text{ D.}$$

which gives $\rho_c = 4.44$ mms. At 2.5 mms. from the axis the accommodation was 3.7 D. and therefore the refraction at this point of the anterior surface in a state of repose was 9.7 D., and the normal, N, is given by

$$\frac{n-1}{N} = 9.7 = \frac{0.06}{N}.$$

This equation gives N = 6.1 mms. The radius of curvature, ρ, at this point can be found from the expression which holds good for all surfaces of the second degree, namely

$$\rho = \frac{N^3}{\rho_c^{\,2}}.$$

This gives $\rho = 12$ mms., while for the same surface in repose $\rho = 6.1$ mms. and the central radius of curvature, ρ_c, = 4.44 mms. These results show that the surface is flattened during accommodation as one proceeds toward the periphery. The surface will, therefore, have the form of a flattened hyperboloid.

140. The curves given in Fig. 92 are taken from Tscherning's and Besio's recent work on the subject: the curves show the lengths of the radii of curvature of the anterior surface of the crystalline at different distances (y) from the axis. The ordinates give the radii in millimeters. The lower curves correspond to a condition of repose, the upper curves to a state of accommodation in three different cases. The figure shows that the curvature diminishes toward the periphery during a state of repose but in a degree differing for different eyes; during accommodation the peripheral flattening is accentuated; the curvatures of the central portions increase while the peripheral curvatures diminish.

141. The flattening toward the periphery of the anterior lenticular surface explains in part the difference which is observed, by skiascopy or otherwise, between the central and peripheral accommodation. Calculations from the data of Tscherning and Besio, according to the

formula $D = \frac{74}{N}$, give as the average difference between the central and peripheral parts about 3 D., while skiascopy and the subjective methods give a difference of 5 to 6 diopters. A part of the accommodative overcorrection must then be attributed to the posterior surface. No direct measurements are at hand establishing the peripheral flattening of the posterior surface, but Grossmann, who studied the

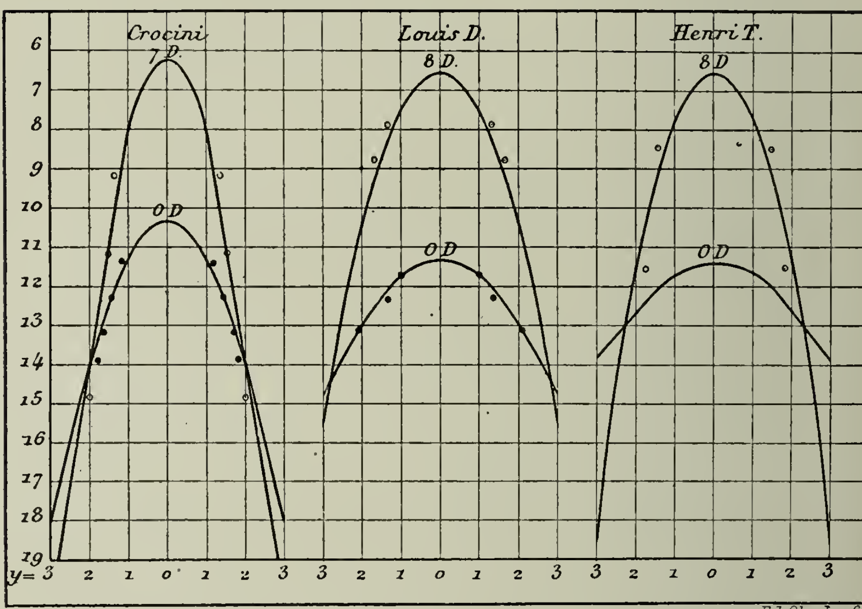


Fig. 92.—Curves Showing the Lengths of the Radii of Curvature of the Anterior Surface of the Crystalline at Different Distances from the Axis. (After Besio.)

accommodative phenomena in a subject having congenital aniridia, has drawn the forms of the images due to this surface and they are analogous to those represented in Fig. 89. In fact the figures of Grossmann indicate that the flattening is much more pronounced at the posterior lenticular surface. Furthermore, the observations of Grossmann show that there is a diminution of the diameter of the crystalline during accommodation. Likewise, according to the investigations of Besio, the increase in the thickness of the lens during accommodation is to be attributed to the flattening of the surfaces near the borders.

Fig. 93 is drawn from the measurements of a living eye as given by Tscherning and show in heavy lines the form of the lens during repose

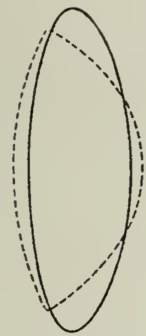


Fig. 93.—Form of the Crystalline During Repose (————) and During an Accommodation of 8 Diopters (. . . . .). (After Tscherning.)

and by dotted lines the shape of the lens during an accommodation of 8 diopters.

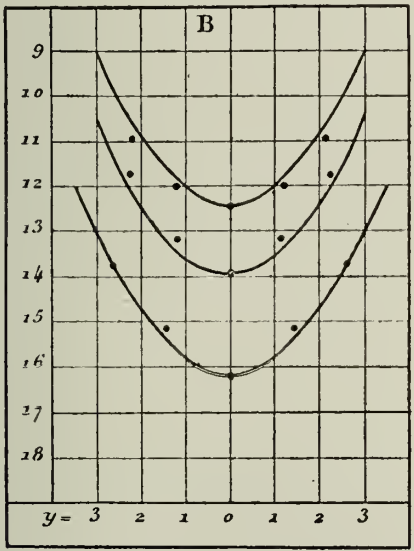


Fig. 94.—Curves Indicating the Lengths of the Radii of Curvature of the Anterior Surface of the Dead Crystalline Lens at Different Distances from the Axis. (After Tscherning.)

142. In the light of the foregoing results the hypothesis of von Helmholtz appears rather improbable, for it is difficult to understand how a relaxation of the zonula can effect a bulging of certain parts of

the surfaces while it causes a flattening of other portions. From a study of the radii of curvature of the anterior surfaces of dead crystalline lenses, Tscherning has shown that there is a flattening at the center and an increase of curvature toward the borders, which is just the reverse of the observations recorded in Fig. 92 for the crystalline under accommodative action. The graphical results of measurements on the radii of curvature of the anterior surfaces of morbid crystallines at different distances from the axis are shown in Fig. 94. A comparison of Figs. 92 and 94 is very instructive. If the living

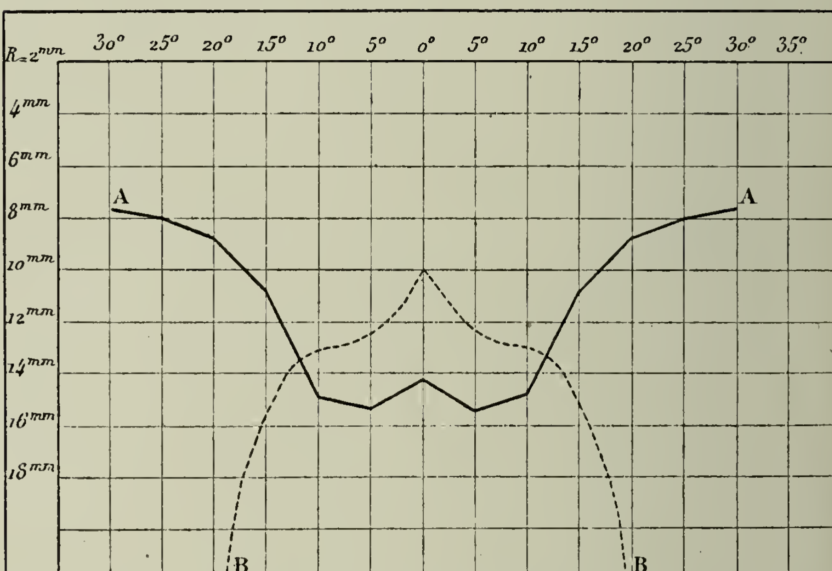


Fig. 95.—Radii of Curvature of the Anterior Surface of the Crystalline Lens of Dead Ox Eye. (After Crzellitzer.)

Curve A corresponded to state of equilibrium and curve B was obtained by traction upon the zonula.

crystalline should assume during accommodation the form of the morbid crystallines there would result a very rapid diminution of the refraction and an accentuation of the spherical aberration. The contrary is, however, experienced.

143. Crzellitzer constructed an instrument by means of which he could exert a traction upon the zonula in all directions at the same time. In his experiments with an ox eye he found that the radius of curvature diminished at the center of the surface, following traction, from 14 millimeters to 10 millimeters, while at 17 degrees from the axis it increased from 10 millimeters to 18 millimeters. The curve A

in Fig. 95 indicates the radii of curvature of the surface in repose or static equilibrium conditions; the curve B gives the radii when the crystalline is subjected to a pulling force along the zonula. The curve A is analogous to the dead human crystalline (see Fig. 94) and the curve B to that of the living crystalline in a state of accommodation (see Fig. 92).

144. The result of these experiments, "which," as Tscherning says, "at first sight may appear paradoxical," is a simple consequence of the structure of the crystalline lens. The nucleus has a much more pronounced curvature than the surfaces of the crystalline lens and its shape is not changed except with great difficulty. The superficial layer can be readily changed in shape and curvature and has been referred to as "the accommodative layer." This diminishes with age and the amplitude of accommodation consequently decreases. By the exertion of a traction on the zonula the peripheral parts must flatten, while at the middle the curvature increases on account of the greater resistance and curvature of the nucleus. The same result will follow, according to Tscherning, if there is no nucleus, as in the case of children, if the curvature and resistance increase toward the center of the lens. The evidence is fairly satisfactory that there is increased resistance as the center is approached since the index of refraction increases in the same direction; the increase of curvature of the central layers is visible in any preparation of the lens.

145. Tscherning has given us an account of the order in which the accommodative procedures and phases occur. By placing a cursor of the ophthalmophakometer above the telescope and requesting the observed person to look at the latter, the following phenomena are observed. There are four apparent phases which occur during an act of accommodation followed by a relaxation. (I) The image of the anterior surfaces descends quickly towards the corneal image and is ultimately hidden behind this. The pupillary contraction begins toward the end of this phase. (II) The small image due to the posterior crystalline surface descends in turn by an abrupt movement. The displacement is less than for the anterior surface image but moves in a curve with its concavity turned toward the middle. The pupillary contraction is greatest at this period. (III) When relaxation of accommodation occurs the posterior surface image ascends to its original position with a rapid movement. (IV) The large anterior surface image re-ascends by a slow, hesitating movement. These four phases are diagrammed in Fig. 96. The corneal image is represented by a large blackened circle (**O**), the anterior crystalline surface image by an open circle (◯) and the posterior surface image by a small full

circle (○). Diagrams I and II indicate the positions of these images during accommodation, III and IV during relaxation. The arrows indicate the directions of movement.

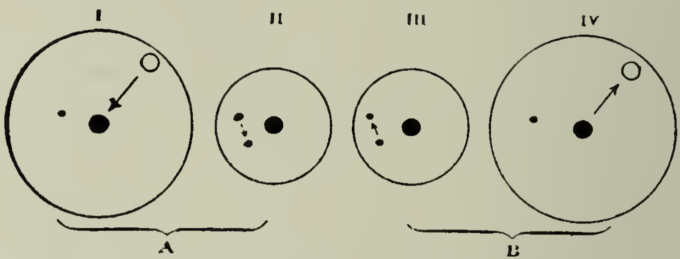


Fig. 96.—The Four Apparent Phases of Accommodation. (After Tscherning.)

Fig. 97 shows the displacements of the image due to the posterior crystalline surface during the maximum effort of accommodation; *C* represents the state of affairs when looking straightforward; *H*, look-

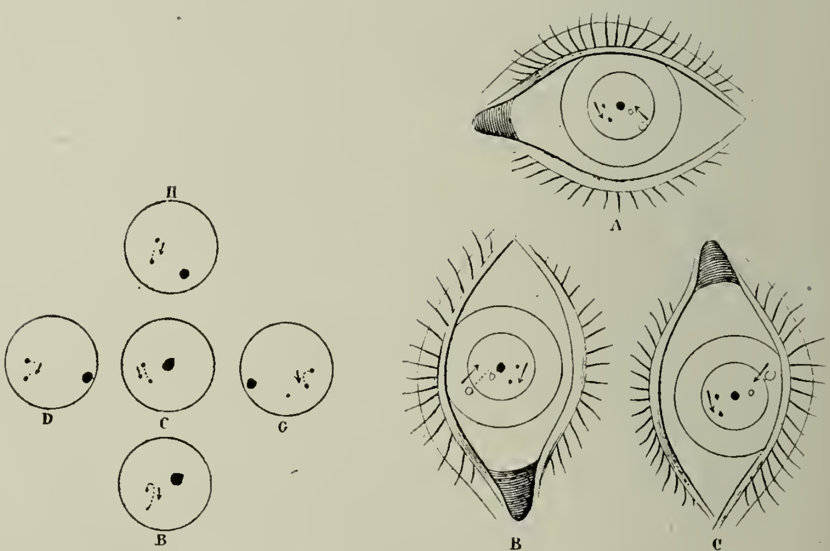


Fig. 97.—Displacements of the Image of the Posterior Surface During Accommodation, Observed with the Ophthalmophakometer. (After Tscherning.)

ing upward; *B*, looking downward; *D*, to the right and *G* to the left. The corneal and posterior lenticular images only are shown; the arrows indicate the direction of the displacement during the act of accommodation.

146. The conclusions which Tscherning has drawn from his experimentation have been included in the rehearsal of his work on accommodation. We shall gather together at this juncture some of the essential points in support of his theory and state them in succinct form.

"(1) The increase of refraction of the lens in accommodation takes place only near the apex of the lens. This is established by a study of the spherical aberration of the eye. Aberration, which is positive when the eye is at rest, diminishes or even becomes negative during maximum accommodation."

"(2) Measurements with the ophthalmophakometer show that the increase of curvature of the anterior surface of the lens is confined to the portion near the summit of the lens. Accommodation is effected by the temporary formation of an anterior lenticonus."

"(3) Experiments made upon the eyes of animals show that traction upon the ligament of the lens produces an increase of curvature near the summits of the surfaces and relaxation produces diminution of curvature."

Hence Tscherning and his collaborators have been led from their researches to the conclusion that the zonula is relaxed when the eye is in a state of repose and that it is in a taut condition or under traction during accommodation.

XIII. THE PUPIL

147. The pupil contracts and dilates under different influences: these movements are rather complex and still without complete or adequate elucidation. In 1812 Maunoir revealed the existence of circular fibers in the iris of the bird; the microscope has since demonstrated the existence of the sphincter muscle of the iris in man. It is known to be a circular muscle-band about a millimeter wide and situated at the pupillary margin of the iris and nearer its posterior surface. The existence of radiating muscle fibers, or the pupil dilator, has been the subject of much discussion. Grunhagen, Collins and others have taught that there is elastic tissue in the iris that effects the dilatation of the pupil when the action of the sphincter is inhibited. In 1894 Juler presented evidence before the International Congress of Ophthalmology to show the existence of a radiating muscular structure of the iris; he demonstrated that these fibers have their origin at the attached margin of the iris and pass to the pupillary margin where they become blended with the sphincter muscle. The movements of the pupil are under the control of the motor oculi and the great sympathetic. Cutting the motor oculi produces a dilatation

of the pupil which is less, however, than that produced by atropine. The pupillary contractions which accompany accommodation and the incidence of light cease together. Hence the contraction which accompanies the incidence of light is produced by a reflex action between the retina and the optic nerve on the one hand and the third nerve on the other. The third nerve fibers and those of the cervical sympathetic causing contraction and dilatation pass first to the ciliary ganglion where they are joined by fibers from the fifth nerve. The several short ciliary nerves, each containing fibers from the three different sources, pass out from this ganglion and proceed to the posterior part of the eye and are finally distributed to the ciliary body and iris. Brown-Sequard produced a contraction of the pupil by concentrating light on an enucleated rabbit's eye. The writer of this monograph has recently had a similar experience with enucleated dog eyes in which it was found that, in an occasional case, the pupil of such an eye responded to light stimulation. This would indicate that light has a direct influence on the muscles of the iris. An irritation of the oculo-motor produces a contraction of the pupil, while an irritation of the great sympathetic at the neck produces a marked dilatation.

The action of mydriatics and myotics is a topic beyond the purview of this work. Briefly, however, it may be stated that atropine produces a marked dilatation of the pupil, paralyzing its movements and those of the accommodation as well. It probably also irritates the terminal fibers of the great sympathetic, thus causing a greater dilatation than would be produced by cutting the motor oculi. Cocaine (5 per cent.) dilates the pupil but does not act upon the accommodation. Scopolamine ($\frac{1}{5}$ per cent.) produces paralysis of accommodation with marked dilatation of the pupil. Eserine (0.5 per cent.) causes a very large contraction of the pupil; under this treatment an eye reaches its maximum accommodation since the decrease in size of the pupillary area produces a reduction of the diffusion circles with a corresponding improvement in visual acuity.

148. *The movements of the pupil.* I. *The pupil contracts under the influence of light.* If it does not do so, but does when light impinges upon the retina of its mate, a complete amaurosis of the eye in question can be inferred. In normal conditions both irides respond, giving usually equality of sizes of pupillary areas, when one eye is illuminated and the other less strongly lighted or even screened. This is due to the consensual action. In darkness the pupil reaches its maximum dilatation so that the iris is often practically invisible; if the iris is not visible at all it can be shown that it is an apparent phenomenon due to refraction through the cornea. The very evident purpose of

the contraction and dilatation of the pupil is to regulate the quantity of light which enters the eye; it acts, therefore, as a *photostat.*

II. *The pupil contracts during accommodation.* The normal iris should not only respond directly and consensually to light stimuli (reflex by the optic nerve) but also when an effort of accommodation is made. Accommodative contraction may exist without the reaction to light and vice versa. Hueck says that the most peripheral portions of the iris show a centripetal movement during accommodation and that this is generally not the case in a reaction to light.

III. *The pupil contracts when the aqueous humor escapes.* The observations of Arlt showed that there was still pupillary contraction after paracentesis had been performed on a dead eye. Some experiments made by Tscherning show that, by inserting the point of a syringe into the anterior chamber and, depressing and withdrawing the piston in turn, the pupil can be made to dilate or contract at will. In fact, by a removal of all the contents of the anterior chamber the diameter of the pupil could be reduced to 1 or 2 mms., and by forcing the injection the iris could be made to disappear. These effects do not appear to be due to pressure, for the eye can be compressed without any change in the diameter of the pupil resulting and it cannot be effected by injecting into or removing liquid from the vitreous.

IV. The pupil is *contracted during sleep* even in amaurotic persons; during narcosis; generally when a person is suffering; at the moment of death the pupil is generally dilated, soon followed, however, by a contraction. The pupillary contraction present during sleep does not inhibit the reaction to light.

V. Under a magnifying glass *rhythmic contractions* are observed corresponding in part to the systole. This is greater when the systole is coincident with respiration.

VI. A *dilatation* occurs during fright; it also occurs during vigorous muscular action or a sharp irritation of any sensitive nerve.

149. *Advantage of the situation of the pupil near the nodal point.* In physical optics, a lens or lens system is often demanded which is *rectilinear.* By this we mean that the image produced shall be free from distortion and the images of straight lines, for example, placed peripherally in the field shall be straight and not curved. This condition of rectilinearity or orthoscopy may be approximated by employing a diaphragm so placed before a single lens as to be at the point through which all rays from the object must pass in order that the subsequent refraction by the lens may produce an image proportionate in all respects to the object. The image will be free from distortion when the so-called tangent condition is fulfilled.

The question may, then, be very appropriately raised: Is there any advantage in the situation of the lens near the nodal point? Distortion in a two-element system is eliminated by a stop placed between the components in such a position as to cause the distorting effect of the front lens to be neutralized by that of the back lens. Now, the refraction by the cornea produces a constriction of the image near the border. The anterior surface of the crystalline lens, however, will have little compensating effect since the pupil is practically in contact with it. The posterior lenticular surface compensates somewhat for the corneal error but not sufficiently to rectify the system. Hence retinal images will be deformed with barrel or negative distortion. Yet without doubt and in spite of the foregoing statements, the position of the pupil near the nodal point of the eye (assuming one nodal point only, without affecting the argument, since the two nodal points

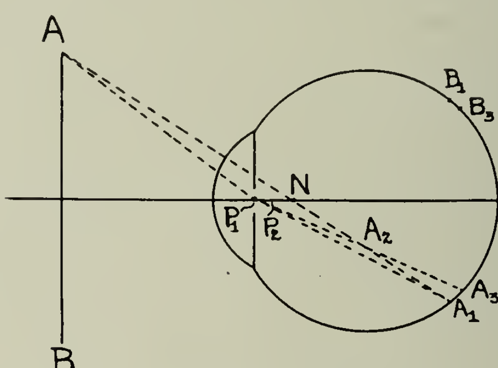


Fig. 98.—Advantage of the Position of the Pupil Near the Nodal Point.

of the eye are so near together) probably plays some part in the correct vision of objects seen indirectly.

150. Young remarked that if the pupil of an eye were to be situated nearer the cornea than it is the apparent size of objects would change whenever an effort of accommodation is made. The image of a point for which the eye is not accommodated forms a circle of diffusion the center of which, corresponding to the middle of the pupil, is frequently brighter on account of spherical aberration. If the pupil is not too large this central portion may be considered an indistinct or vague image of the point. Let us assume that, in a state of repose, the eye is focussed for an object AB as in Fig. 98. The image of the point A is found at A_1 on the line AN passing through the nodal point N. The image is, however, moved forward to A_2 during the act of accommodation. Let P_1 represent the center of the pupil of

entrance: therefore, to find the place where the diffuse image is formed on the retina, the ray AP_1 is drawn passing through the point P_1. This ray, after refraction and after passing through the middle point P_2 (P_1 and P_2 are practically coincident, however, being in reality but 0.7 mm. apart) of the pupil of exit and through A_2, the position of the accommodated image, will form a diffuse image upon the retina at A_3 and the image of the entire object A_3B_3 is smaller than the distinct image A_1B_1. "In the human eye we may observe a slight effect of this kind using our accommodation while observing distant objects; it is more pronounced when the pupillary action is replaced by a stenopaic opening at some distance from the eye" (Tscherning).

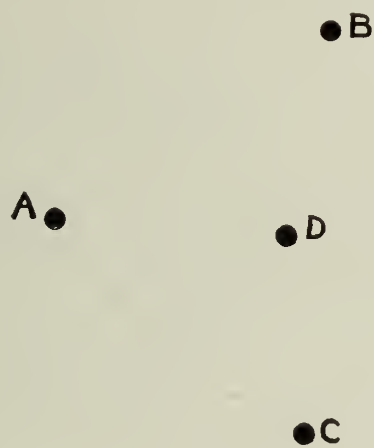


Fig. 99 A.—Test for Showing that the Eye is not Rectilinear.

151. That the eye is not rectilinear may be proven by some simple experiments due to Helmholtz.

I. Place upon a table a small piece of paper, A, Fig. 99 A, which shall serve as a fixation point and then put two other small objects, B and C, as far as possible from A so that they may be seen distinctly in indirect vision. While fixing A, the experimenter endeavors to put a fourth piece, D, in a line joining B and C. Generally D will be too far inwards toward A thus giving the barrel-shaped distortion.

II. If a strip of paper with parallel borders about 8 to 10 centimeters in width is taken and the center visually fixed, the borders appear concave towards the point of fixation, hence the strip appears larger at the middle than at the ends.

III. An experiment of a similar kind consists in placing a circular piece of cardboard in the periphery of the visual field; it is seen elongated in the horizontal direction above or below, while when laterally viewed it appears elongated in a vertical direction.

IV. Helmholtz constructed from theoretical considerations his celebrated hyperbolic chess-board of which Fig. 99 B is a representation reduced in the ratio of 1 to 8. When this was viewed at a large distance the lines appeared to have the curvatures which they were given; on moving it nearer and nearer he found that the curvatures diminished and that at 20 centimeters distance from the eye the curvatures disappeared, agreeing with his calculations. On closer approach the lines assumed the reverse curvatures. Tscherning re-

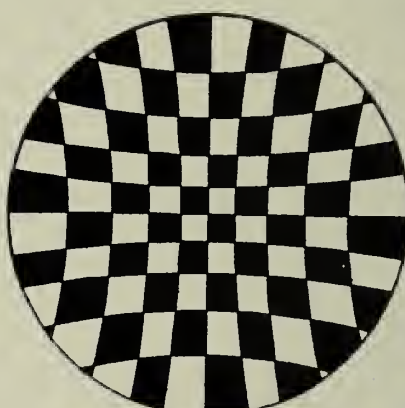


Fig. 99 B.—Hyperbolic Chess-board of Helmholtz.

peated this experiment with an artificial eye, practically duplicating the dioptrics of the eye, together with a hollow hemisphere of ground glass of practically the same curvature as that of the retina of the normal eye. He found that as long as the object was remote the image was like it; very near to the drawing the lines of the image became concave on the inside. The point at which the image of the figure appeared most rectilinear was at 20 centimeters from the artificial eye. These results are interpreted to indicate that all these deformities are dependent primarily upon the form of the retina.

The query has been raised by us as to whether or not there is any advantage in the position occupied by the pupil or, in other words, could it not have been more advantageously situated elsewhere? Considering the hemispherical shape of the retina, we can proceed to project upon a screen visual lines, both direct and indirect, drawn

from *retinal points equally spaced as to arc measurements* in three apparent ways. These are shown in Fig. 100. In (I) of this figure the various points are projected straightforward by lines perpendicular to *EF;* we see that the space image is extremely constricted in size and narrowed at the periphery. In (II) projection is carried out through the center *C;* the image expands rapidly toward the periphery. In (III) we have stereographic representation, in which projections of rays are carried out through a point *P* on the corneal surface. This gives us the nearest approach to rectilinearity: that is to say, if the pupil were reduced to a point and situated at the anterior pole of the retinal hemisphere, the image would be as rectilinear as possible. The pupil is, however, situated behind the anterior corneal

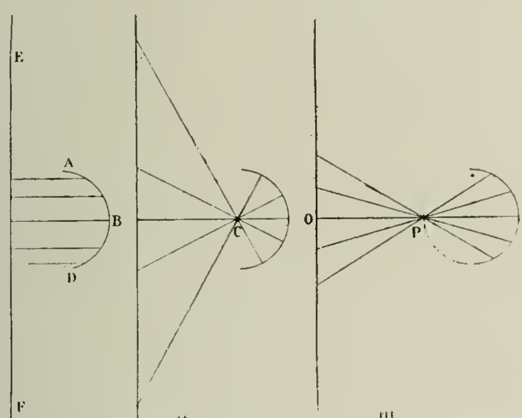


Fig. 100.—Deformity of Image Due to the Shape of the Retina.

pole and the incident rays suffer spherical aberration in the peripheral regions, hence the impossibility of rectilinearity when a distant field is under observation with fixation at a definite point. The aberroscope shows the presence of this distortion. But on accommodation it is found that the aberroscope generally shows no distortion and even an over-correction giving evidence of the formation of an anterior lenticonus. At the same time the iris together with the anterior lenticular surface is displaced forward toward the corneal pole. It therefor seems possible to explain the changes observed by Helmholtz in using the chess-board as due to (1) elimination of spherical aberration by contraction of the pupil, (2) the closer approach of the pupillary area to the corneal apex and (3) the change in the obliquity of the rays incident upon and emergent from the crystalline lens due

to changes in curvature of the lenticular surfaces. All of these effects are probably intimately tied up with retinal curvature effects.

152. *The relation between pupillary area and asthenopia.* A subtle and synchronous balance between retinal perception, uveal stimulus and iridic response must exist if the iris is to perform its functions as a photostat and diaphragm. It is probable that a disturbed equilibrium of these functions is the cause of asthenopia in low degrees of ametropia in which small corrections are advantageous. In cases where quarter diopters appear to relieve asthenopia it will often be found that the pupils are comparatively large; hence asthenopia may be experienced as much on account of the size of the pupil as on account of errors of refraction. In a case of hyperopia of low degree, for example, with extremely large pupil, we have a comparatively small central area of diffusion due to the refractive area covered by a much larger area of diffusion and illumination. A slight error of accommodation would either sustain or increase the discrepancy. If, then, the aberration is to be abolished, the iris must receive an increased stimulus to bring about a contraction of the pupil in excess of that which is associated with accommodation. A correction of the slight error eliminates the diffuse central image but the area of total illumination and peripheral aberration is increased; the fact, however, that the lens improves vision and relieves asthenopia is satisfactory proof that the aberration is dispelled, indicating an increased iridic contraction. And again, in normal pupils with retinal perceptive powers excellent, and errors of refraction slight, retinal stimulus will prompt contraction of the pupil sufficient to exclude aberration. In cases with large pupils it is probable that prolonged efforts of iridic contraction will cause a fatigue of the iris and the resultant asthenopia. See **Lenses and prisms, Ophthalmic** in this *Encyclopedia*, Volume X, pages 117-126.

XIV. APPLICATIONS OF THE LAWS OF CONJUGATE FOCI TO RETINOSCOPY AND OPHTHALMOSCOPY

153. *Retinoscopy.* Retinoscopy may be defined as the measurement of ocular refraction by means of the real or apparent movements of the fundus reflex. The laws governing conjugate foci are applicable to these objective methods since the eye, although a complicated system, is equivalent to a single convex refracting surface with a posterior focal length of about 20 mms. Object and image positions are always reversible in a lens system; subjectively, light from an object twenty or more feet away will form upon the retina of the human eye of proper axial depth a distinct image without any effort of accommodation. The incident light is, therefore, parallel, being brought to a

focus upon the retina; infinity and the retina are, then, conjugate points. This retinal image may, in turn, be adopted as the luminous object and the refraction may be considered as taking place from the denser (water equivalent eye) to the rarer external medium, with the emergent light parallel. Or again, assuming a myopic eye, fixing at infinity, we know that the image due to the refractive apparatus will be formed in the vitreous; this will, however, produce a diffuse, enlarged image upon the retina. This retinal image, whatever its size or character, may then be considered as the new object and its conjugate found at a finite position in space. The fundamental law of refraction at curved surfaces, which has been previously expressed in the section on *Ocular dioptrics* as

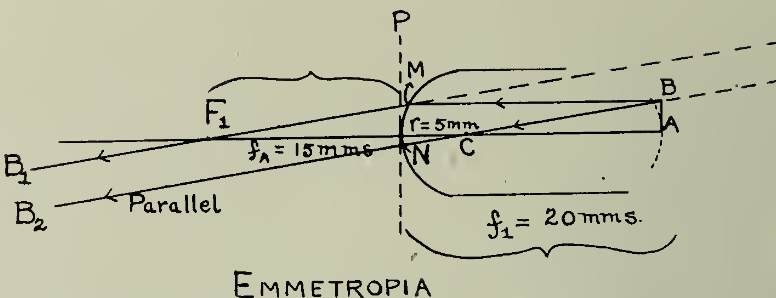
$$\frac{n_1}{f_1} + \frac{n_2}{f_2} = \frac{n_2 - n_1}{r}.$$

holds equally well in ocular calculations when the illuminated area upon the retina is taken as the object and its conjugate in space is desired, provided due regard be had to the algebraic sign of the radius of curvature, r. As an illustrative case, let us assume the axial depth of an eye to be 23 mms. and that it is desired to find the conjugate to a point upon the retina situated at this distance from the cornea. Assume the constants of the reduced eye; our data are, then, $f_1 = 23$ mms., f_2 is to be calculated, $r = -5$ mms. Since the light is now considered as passing from the more dense to the less dense medium, $n_1 = 4/3$ (water) and $n_2 = 1$ By substitution of these values in the above equation one obtains

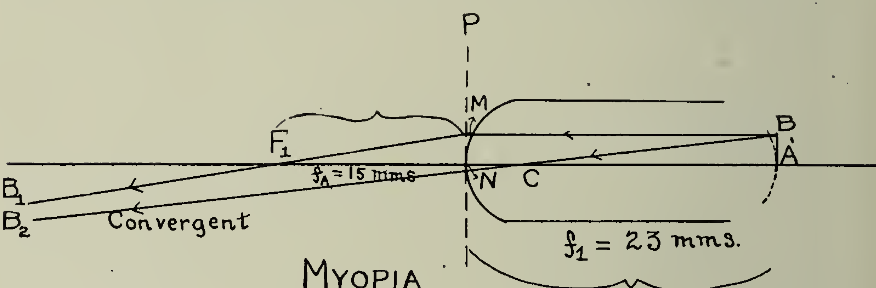
$$\frac{4/3}{23} + \frac{1}{f_2} = \frac{1 - 4/3}{-5}$$

which gives, upon solution, $f_2 = 115$ mms. $= 11.5$ cms. as the conjugate focal length in air measured from the cornea in a direction contrary to that in which the posterior focal length, f_1, is measured. This value of f_2 corresponds to the far point in a myopia of 8.7 diopters. Light diverging from a point on the retina would then be received as light converging toward a point situated 11.8 cms. from the cornea. In a case of hyperopia in which, for example, the depth of the eye, f_1, may be taken as 18 mms., calculations will show that

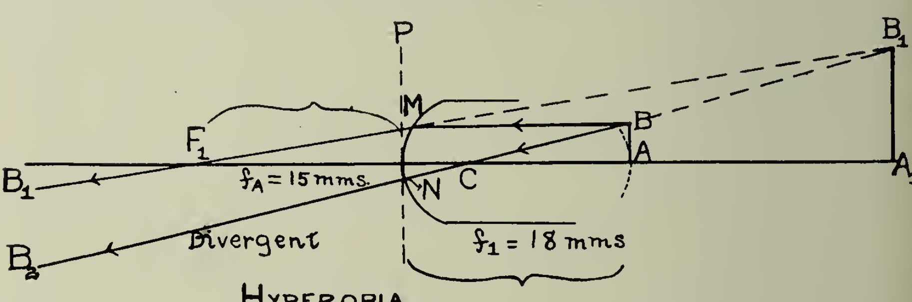
$$\frac{4/3}{18} + \frac{1}{f_2} = \frac{1 - 4/3}{-5}$$



(A).—Illustrative of the Conjugacy of Foci and Nature of the Emergent Beams in Plane Mirror Retinoscopy when Emmetropia Obtains.



(B).—Illustrative of the Conjugacy of Foci and Nature of the Emergent Beams in Plane Mirror Retinoscopy when Myopia Obtains.



(C).—Illustrative of the Conjugacy of Foci and Nature of the Emergent Beams in Plane Mirror Retinoscopy when Hyperopia Obtains.

Fig. 101.—Illustrative of the Conjugacy of Foci and Nature of Emergent Beams in Plane Mirror Retinoscopy when (A) Emmetropia, (B) Myopia and (C) Hyperopia Obtains.

gives $f_2 = -135$ mms. $= -13.5$ cms. This distance f_2 is then to be measured from the cornea toward the retina, which shows that the point conjugate to the retina does not exist in space but lies behind the retina. That is to say, we have a virtual object which means that

the rays emerging from the eye under these conditions will be divergent but that, by projection backwards, they can be made to meet at a point back of the retina. These various conditions, using an illuminated retinal area as an object, are diagrammed in Figs. 101 (A), 101 (B) and 101 (C), representing respectively emmetropia, myopia and hyperopia. The center of curvature is represented as at C and occupies the same position relative to the principal refracting plane, assumed tangent to the corneal surface, in all cases since all emmetropic and ametropic conditions of the eye are diagrammed and considered as dependent upon axial depth and not upon curvature or indicial variations. The anterior focal point is represented as situated at F_1 such that the distance f_A, representing the anterior focal length, has a value of 15 mms. The radius of curvature of the refracting surface is 5 mms.; the posterior focal length $f_1 = f_P$ of a normal eye is taken as 20 mms. The single nodal point is coincident with the center of curvature. For the sake of clarity the diagrams do not show the paths of the rays incident upon the eye and their positions in the eye after refraction; an illuminated retinal area AB is exhibited in each case, however, and this plays the part of a luminous object in our subsequent discussion. The paths of the emergent rays and their conditions of parallelism, divergence or convergence may be readily established by the application of a few fundamental principles of geometric optics. The ray BM, being parallel to the principal axis will, after refraction by the curved surface, pass through the anterior focal point F_1. A ray, BC, passing through the center of curvature or nodal point C will continue without subsequent deviation or refraction. The point at which two emergent rays, such as B_1M and B_2N, meet determines the position of the image of B. From the figures we see that the light emergent from the illuminated retina of an emmetropic eye will be parallel and hence meet at infinity; in myopia a real, inverted, aerial image will be formed by the convergent light somewhere between infinity and the eye; in hyperopia the emergent rays are divergent and would, by projection, intersect at a point behind the retina.

154. There is, therefore, every reason to believe that light from an illuminated retina, which acts as a luminous source, emerges from the eye and can be intercepted by another eye if a proper device is at hand to permit of its reception. Ordinarily the pupil of an eye is seen black because the observer is never in a position to receive the light from the retinal image of a source sufficiently bright to enable the fundal light to be received. An extraneous source of light, such

as a lamp, cannot be used in the direct line of sight for the obvious reason that the observer's own head would come between the observed eye and the light used, thereby cutting off the source of the retinal illumination necessary to the production of the returning rays. To overcome this difficulty the observer's eye must be in a line with the direction of the entering ray. For this purpose a mirror having a central aperture and known commonly by the name of *retinoscope* or *skiascope* is employed. This method in essentials was discussed by Cuignet in 1873 and was employed by him in ocular refraction but he attributed the phenomena to the cornea instead of the fundus oculi. It remained for Parent in 1880 to specially develop the method and give it its correct explanation. Briefly, light from some external

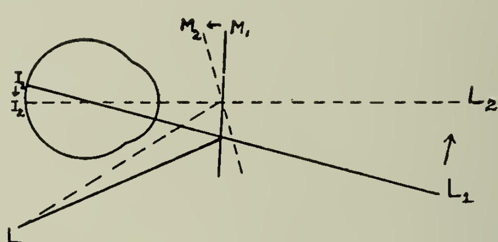


Fig. 102.—Illustrating Movements of Mirror and Reflex in Skiascopy with the Plane Mirror.

L, lamp; M_1, first position of mirror; L_1, image which it forms of the lamp; I_1, retinal image.
M_2, second position of the mirror; L_2, image of the lamp; I_2, retinal image.

source is received by the mirror and reflected into the observed eye where it comes to a more or less well defined focus on the retina. The returning light is, however, diffused by the choroid and not the retina, which is transparent in health, and gives to the reflex its characteristic reddish color. In retinoscopy and ophthalmoscopy the sole function of the mirror is to supply the illumination; the intensity of the beam and the brightness of the fundus reflex are dependent, however, upon the nature, the focal length and the aperture of the mirror.

155. It is common practice at present for the observer to take his position about one meter from the patient whose eye he illuminates with a *plane* mirror. By rotating the mirror about a vertical axis he sees the luminous spot thrown by the mirror flit to and fro horizontally across the face and vice versa, the spot traveling in the same direction as the mirror is rotated. By throwing the light upon the pupil, the fundus is illuminated and it can be shown that the direction of motion of the *retinal* image is always in the same direction as that in

which the mirror is rotated provided a *plane* mirror is employed; the contrary condition or direction of retinal image holds when a concave mirror is employed. An examination of Fig. 102 will show this clearly: L represents the lamp, M_1 the first mirror position, M_2 the second position, L_1 and L_2 the corresponding positions of the images of the lamp L formed by the mirror and I_1 and I_2 the retinal images. The arrows show the directions of motion. *The image upon the retina always moves in the same direction as the plane mirror is rotated, irrespective of the ametropic condition present; the direction of the movement of the reflex and its accompanying shadow is another matter entirely and dependent upon other phenomena for its existence.*

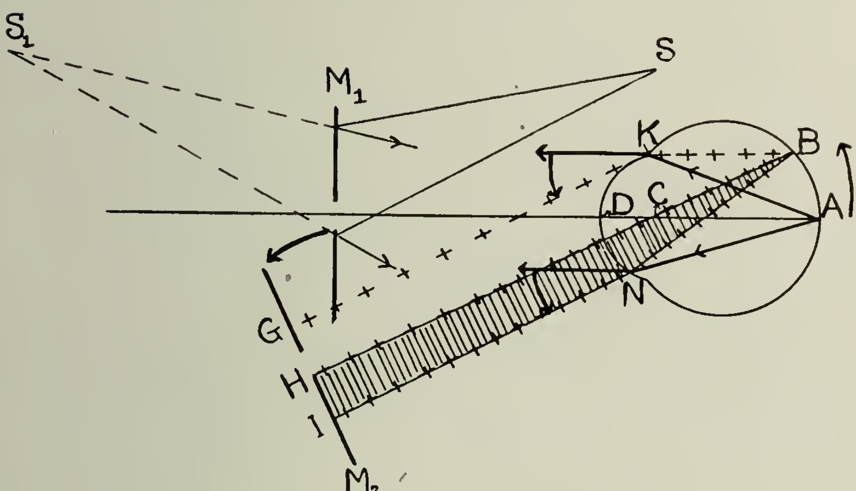


Fig. 103.—Detailed Diagram of Mirror, Retinal Image and Reflex (Shadow) Movement in Emmetropia.

156. Having, then, illuminated the retina and obtained the red reflex, the mirror is rotated and the observer watches the reflex as it moves across the pupil. As a matter of fact it is the boundary between the illuminated and non-illuminated portions of the fundus reflex which is noticed or what is technically known as the *shadow*. The direction of the reflex or shadow movement, whether "with" or "against" the rotation of the mirror, depends upon the refraction of the eye, the nature of the mirror and the position of the observer. Figs. 101 A, B and C show the nature of the emergent rays in various refractive conditions (simple ametropias) of the eye. Figs. 103, 104 and 105 attempt to show:—(a) the plane mirror in two positions, M_1

and M_2, (b) the cone of light, *AKN*, emerging from the retinal point *A* (drawn as heavy lines), (c) the cone of light, *KBN*, emergent from the luminous point *B* after rotation of the mirror from position M_1 to M_2 (indicated by dotted lines), (d) the nature of the emergent rays, whether parallel, convergent or divergent and (e) the portion of the pupil which appears luminous. The diagrams are of necessity exaggerated and the mirror in its second position not only rotated but slightly displaced in order to emphasize certain points. In Figs. 103 and 104, representing emmetropia and hyperopia respectively, a portion of the emergent cone of light, *AKN*, is intercepted by the observer's eye situated back of the aperture in the mirror in position M_1; this being the primary position the pupil of the eye under observa-

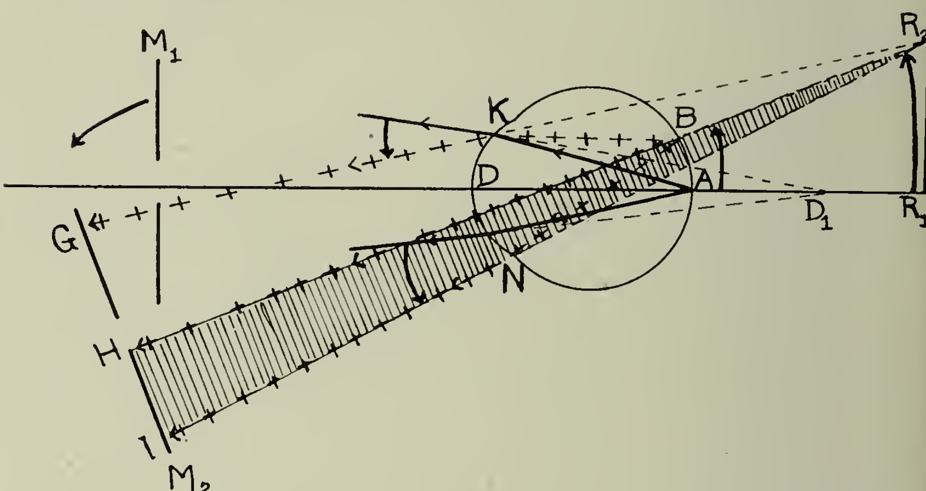


Fig. 104.—Detailed Diagram of Mirror, Retinal Image and Reflex (Shadow) Movements in Hyperopia.

tion is seen filled with a reddish glow: upon rotation of the mirror into a secondary position, as M_2, a portion of the emergent cone *BKN*, passing into space between the limits of *KG* and *NI* as diagrammed, is intercepted and received by the observer. The eye sees as luminous that portion of the pupil which sends rays to it, i. e., the portion *KD* in Figs. 103 and 104, while *DN* is dark because the rays which come from this point are not received by the observer or are, as another mode of expression, intercepted by the iris of the observer. We see, therefore, that in emmetropia and hyperopia, using a plane mirror, the reflex will travel in the same direction as that in which the mirror is moved and will be followed by a shadow due to the fact that the light from a portion of the pupil does not reach the observer's eye.

The light apparently moves on the retina in the same direction as it in reality does. If, on the contrary, a sufficient amount of myopia exists in the observed eye such that the conjugate to the retinal point A is at O_1 between the observed and observing parties, it can be seen from Fig. 105 that the light or reflex moves in the contrary directions to

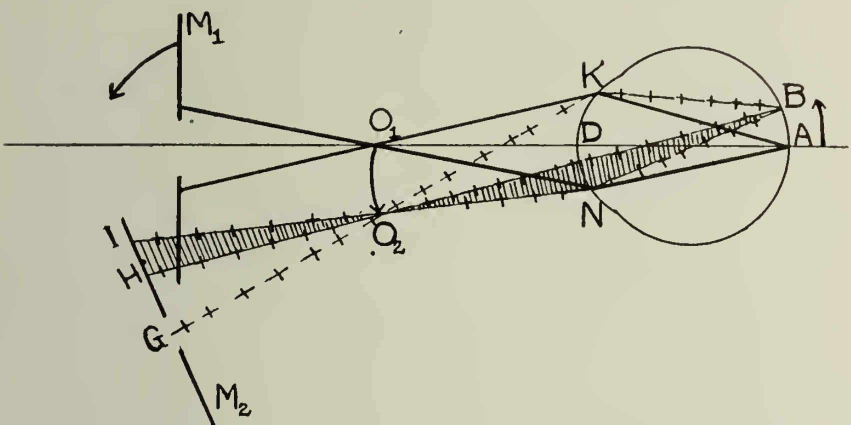


Fig. 105.—Detailed Diagram of Mirror, Retinal Image and Reflex (Shadow) Movements in Myopia.

the mirror rotation, because the light comes to the observer from an inverted aerial image which the operator observes. These two images are represented as being at O_1 and O_2 and the arrows show that their motions are contrary to those of the retinal images A and B. Likewise, a casual survey of Figs. 104 and 105 will show that the relative

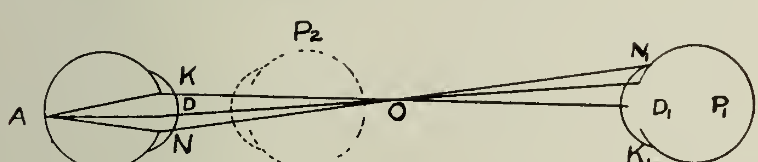


Fig. 106.—Diagram Illustrating Leroy's Theory of Skiascopy.

orders of the rays KG, DH and NI are reversed in the two cases; it can also be seen that further rotation of the mirror as shown in Fig. 105 will cause the cone of light O_2HI to enter the mirror and hence cause the observing eye to see the luminosity travel from K to N. This condition is illustrated in a further and possibly simpler manner in Fig. 106. Let A be an illuminated point of the retina of the observed eye, supposedly myopic, and O its aerial image. The luminous

cone AKN leaves the observed eye, giving the aerial light cone KON of which, however, only the portion OD_1K_1 enters the observer's eye. Hence to the observer the portion of the pupil KD will appear luminous while DN is dark because the rays which come from this part are intercepted by the iris of the observer.

157. The movements of the reflexes and shadows as seen in the pupil have been discussed with some degree of fullness in connection with the preceding diagrams in order to correlate the laws of conjugacy of foci with the fundamentals of skiascopy. But nothing has as yet been said about the relative positions of the observed and of the observer. This is in practice one of the most important considerations. Referring again to Fig. 106 it will be seen that if the observer should move his eye from position P_1 to that indicated at P_2, the patient still fixing infinity and with accommodation properly relaxed or under a complete cycloplegic, there would be a reversal of the direction of movement of the shadows in the two positions. That is to say, in position P_1, under the conditions diagrammed, the movement would be against that of the mirror and therefore to be interpreted as *myopia;* in position P_2, however, the motion will be with the mirror indicating a *hyperopic condition with respect to the far point O of the observed eye.* The point or position O is, as has just been stated, the far point of the patient's eye; it is, then, the meeting point of all rays conjugate to the retina; it is the *neutral* or *reversal point* skiametrically. If, therefore, the image of the luminous retinal point formed in space at O is at the nodal point of the operator no motion of reflexes or shadows will exist but the pupil of the patient will appear uniformly illuminated. This is due to the fact that the aerial image O, falling at the nodal point of the observer's eye, becomes in and of itself an illuminated object which sends out to the retina in all directions rays which are not acted upon by any optical apparatus to produce an image anywhere. So long as there is any single point of the luminous retina which has its image at the nodal point of the observer's eye the fundus will be fully illuminated. If, therefore, the nodal point of the observer's eye is between the observed eye and its far point, whether this be the natural or artificially produced point, the shadow movements will be contrary to those experienced when the observer's nodal point is outside or more remote from the patient's eye than its punctum remotum. The natural far points may, however, range theoretically between minus infinity and extremely small finite quantities dependent upon the degree of hyperopia or myopia present. For emmetropia the punctum remotum is at infinity; assuming a point twenty feet away from such an eye to be sufficiently remote as to be

considered at infinity it can readily be seen that retinoscopy could not be successfully practised under such conditions. As a result an arbitrary or artificial far point is produced by the addition of such a lens quantity to the normal eye as would bring the skiametric reversal point to any point desired. Since light emerges as parallel rays from a normal eye fixing at infinity, the addition of a + 1 D. S. before this eye will cause these parallel emergent rays to focus at 40 inches or 1 meter. The observer stationed at this point would, therefore, be at the reversal point of such an eye thus optically modified and would view a fully illuminated pupil free from shadow movements. When the observer, working at forty inches, with a + 1 diopter lens before the eye, the other being occluded by a cover, sees a "with" motion when using a plane mirror he is justified in concluding that hyperopia exists and continues to add plus lenses until the reversal is reached. In case the motion is "with" when no lens is present to compensate for the "working distance" but is "against" when such a lens is inserted, the observer knows that a myopia of less than the dioptric value of the working distance is indicated. When an "against" motion exists before any working distance lens is inserted the operator realizes that he has a case of myopia of greater amount than that represented by the dioptric equivalent of his working distance. The one essential, therefore, in skiascopy is that the position of the observer's nodal point shall be at the conjugate focus of the retina of the observed eye. The operator, being thus desirous of bringing this conjugate focus to his own nodal point, must always add algebraically to the total lens quantity in the trial frame the negative dioptric value of the distance at which he has worked. For example, the artificially fixed far point is to be 1 meter; let us assume that a total lens quantity of + 4 D. S. before an eye barely produces reversal at this distance. The difference between the actual far point of this eye and the one diopter of artificial myopia for the working distance of a meter, or + 3 D. S. in this case, expresses the strength of the auxiliary lens which must be placed before this eye to make infinity and the retina conjugate foci. If, again, with observation at 26 inches, a — 2.50 D. S. neutralizes the shadow movement or just causes reversal, the total correction indicated is a — 4.00 D. S. The following is a digest of fundamental rules in practical skiascopy using a plane mirror; if the mirror is a short focus concave the movement is in every case the opposite of that specified but the calculations are identical. (1) The shadow movement is *with* in all cases of refraction in which the punctum remotum is negative or, if positive, behind the observer's nodal point. If the punctum remotum is between the observed and observ-

ing eyes the movement will be *against*. The shadow is neutralized when the far point coincides with the observer's nodal point. (2) The neutralizing lenses are those which overcorrect hyperopia and under-correct myopia to a degree equal to the dioptric distance at which the observer operates.

158. The factors upon which the *rapidity of movement* of the light on the retina and the form of the light area depend are worthy of brief consideration. The speed with which the light and shadow appear to travel across a pupil depends upon the rapidity of the real movement of the light area upon the retina and upon the magnification of the retina. The rapidity of the real movement on the retina is determined by (a) the rate of movement of the mirror by the observer, (b) the distance of the mirror from the observed eye, (c) the distance of the original source of light from the mirror and (d) upon the distance of the retina from the nodal point of the observed eye. The rapidity of the *apparent* movement of light in the pupil is much more dependent upon the extent to which the retina and the real movement of light upon it are magnified, than upon the actual rate of the real motion. It is found that the closer the observer's eye is to the point of reversal the more is the real movement of light upon the retina magnified and hence the swifter it appears. The farther the observer's eye from the point of reversal the less is the real movement of light on the retina magnified, since the observer receives rays from an increasing area of the retina and more and more of the retinal image occupies the same space in the pupil.

159. The *form of the light area* upon the retina will be circular except under certain conditions in astigmatic eyes. If the light is perfectly focussed upon the retina the light area will be circular because that is the form of light source employed in practice. If the light is imperfectly focussed, however, the circular pupil gives its form to the resulting area of diffusion. In eyes free from regular and irregular astigmatism and aberration effects the form of the light area varies with the distance of the observer's eye from the point of reversal. If the magnification of the retina is of such a slight degree as to permit of the whole of it being visible in the pupil at one time, the light area will appear circular. When, however, the point of reversal is approached, in which case the magnification of the retina prevents all of the retinal light area being seen at one and the same time, it will be found that only a portion of its outline is visible as an arc of a greatly enlarged circle. The nearer the observer comes to the point of reversal the closer will the boundary between light and shade approach a straight line; in fact, when the eye is almost corrected, one

sees the glow very bright and its border very nearly straight. This straight ocular border is, however, a portion of the boundary of a circle and hence will show itself in whatever direction or meridian the mirror may be rotated; this is in contradistinction to the "band-like" appearance in astigmatism in which the direction of the border always conforms to one or the other of the principal meridians. That the form of the light area is due to the superposition of circles of diffusion of the same form as the pupil of the observed eye can be readily demonstrated by using as a luminous source a very long, bright ribbon of light. In this case the border of the ocular glow remains straight even in the event of strong ametropia because the superposition of the circles of diffusion cannot produce a circular form. Furthermore, if the pupil is given a triangular shape by using a stenopaic opening of this form before the eye under observation, the shadow will be found to retain its rectilinear border, for triangular diffusion spots cannot give a round form to the diffusion area.

160. Our discussion has thus far dealt with the skiascopy of uniform axial ametropic conditions or the equivalent thereof. The determination of *astigmia by skiascopy* rests upon the fundamental principles previously rehearsed, but two meridians of unequal power must be considered in astigmatism. The movement of the retinal image being of necessity in the same plane as the mirror movement, which is at right angles to its axis of rotation, it is the refraction in a single meridian only corresponding to that plane which is determined in retinoscopy. The axis of mirror rotation can, however, be made to correspond to any meridian of the eye which it is desired to examine, hence it is possible to determine separately the refraction in any two meridians at right angles to each other such as exist in regular astigmatism. The points of reversal for the meridians of greatest and least refraction being known, the value of the interval of Sturm, which represents the astigmatic error, is known.

Various methods are used in the practice of skiascopy in the determination of the astigmatic error: many operators neutralize each meridian separately with spheres, while others first neutralize one meridian with spheres and then, without removing any lens quantity present, proceed by the use of cylinders to bring the second refracting meridian to the same point of reversal. The objection to this latter method is, of course, the liability to error in placing the cylinder axially correct. It must be remembered in the calculation of the astigmatic error by the first of these methods that the optical deficiency of the eye is considered as made up essentially of two cylinders at right angles to each other, although the value of one of these cylinders

may be zero as in simple astigmatism, and that the maximum power of a cylinder is always at right angles to its axis. If, then, the mirror is turned about a horizontal axis so as to sweep vertically up and down over the eye, the observer neutralizes by means of spheres the ametropic error in the vertical meridian; i. e., he brings the far point of the observed eye in a vertical meridian to his own nodal point. For example, if the meridian with its axis at 90° requires + 3 diopters to bring about a reversal at one meter and the meridian with its axis at 180° requires + 4 diopters, each meridian being operated upon separately, then the total lens quantity needed to cause reversal simultaneously at one meter is + 3 cyl. ax. 90° ⊃ + 4 cyl. ax. 180°. This is equivalent to + 3 D. S. ⊃ + 1.00 cyl. ax. 180° and the correction for this eye, allowing one diopter for the artificial myopia at the working distance, is + 2 D. S. ⊃ + 1.00 cyl. ax. 180.

161. It is as true of the astigmatic as of the non-astigmatic eye that the image of the pupil becomes magnified as the point of reversal is approached. Hence, when the observer's eye is nearer to the point of reversal for one meridian than it is for the second meridian, the retinal image is more magnified in the direction of the principal meridian to which the nearer point of reversal belongs. When the observer's nodal point is at the point of reversal for one of the observed meridians, the retinal image becomes indefinitely magnified in the direction of this meridian while it is magnified comparatively little in the direction at right angles to it. Every retinal point appears in the pupil, therefore, as a line running in the direction of the principal meridian and the retinal light area assumes the form of an elongated *band of light* running in the direction of the meridian which has its reversal point at the observer's eye. In order to bring out this band-like appearance it is necessary to secure as perfect focusing as possible in the principal meridian at right angles to the one in which the band is sought. Hence the principle, developed by Jackson, that "the band-like appearance is most perfectly developed when the observer's eye is at the point of reversal for one principal meridian and the immediate source of light at the point of reversal for the other principal meridian."

162. *Aberration* and *irregular astigmatism* add to the difficulties of making an exact determination of the refractive condition of an eye. Spherical aberration appears under the forms known as positive and negative, and is the condition in which, during the process of neutralization, two areas arise, one of which is central and the other peripheral, in which the refraction is not the same. The peripheral refraction is stronger than the central in positive aberration and weaker in

negative aberration. In the positive form, when the point of reversal for the center of the pupil is close to one meter for example, the peripheral illumination grows broader and will often crowd in upon the smaller central illumination, causing the observer to believe neutralization has been accomplished or even an over-correction given because of the reversal in the peripheral regions. The operator must therefore regard the motions in the central portions of the pupil. The area in the center of the pupil of comparatively uniform refraction is the *visual zone* and is the portion which is of practical importance for purposes of distinct vision. The cause of the paracentral shadow is explicable by reference to Fig. 107. Assume the patient's eye emmetropic but possessed of a strong positive spherical aberration. The rays coming from some luminous point of the retina will then have the position indicated in Fig. 107. When the observer's nodal point

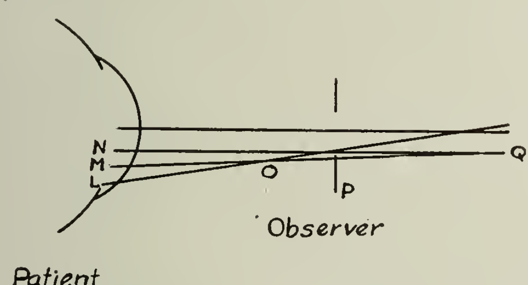


Fig. 107.—Illustrative of the Paracentral Shadow.

is at P he will receive the rays NP and LP and will see as luminous the portions of the observed pupil corresponding thereto, while in the pupillary region corresponding to M there will be no luminosity since the ray MOQ does not enter the observer's pupil. The observing eye would, therefore, see a bright center separated from a luminous peripheral area by a dark ring. If P be displaced a little downwards, so that the pupil can receive all the rays drawn in the figure, the whole will then appear luminous, but the rays coming from the upper portion of the observed eye (not drawn in the figure) will be then affected in that some of them will be occluded from the observer's eye giving rise to the paracentral shadow. A comprehensive and clear account of the appearances of positive and negative aberration effects as the observer moves with his mirror away from the point of reversal for the most myopic part of the eye can be found in Jackson's *Skiascopy.* Spherical aberration is ordinarily not seen in undilated pupils (whether this dilation be natural or by drugs is immaterial);

while the positive form is common to the great majority of eyes it is usually too slight to cause any inconvenience in retinoscopy when the pupil is of normal size.

163. *Irregular astigmatism* exhibits itself under the retinoscope as a more or less broken reflex giving no definite shadow when the neutralization has been carried to the approximate reversal point. If this irregularity, which may have its seat either in the cornea or the lens, is accompanied by a high degree of ametropia the pupillary shadows may be fairly distinct but as higher dioptric powers are inserted before the eye the shadow loses its definite form, thus permitting of an approximate correction only. Irregular astigmatism of the lens due to spicules pointing in from the periphery is often exhibited in retinoscopic examinations and is rarely seen with the ophthalmoscope in its incipient stages.

164. *Conical cornea* is a variety of irregular astigmatism in which the cornea bulges forward in the shape of a cone which may or may not have its apex at the anterior pole of the eye. The result is a highly myopic condition in the apicial region with a diminishing refraction toward the periphery. Under the retinoscope, opposite movements for the center and periphery may occur; the outer portions of the shadow move comparatively rapidly while the central portions are sluggish and may appear stationary. This gives rise to the peculiar appearance of the reflex which has a "swirling" motion around the apex of the cone.

165. *Scissor movement* is a term applied to the retinoscopic appearance of the pupil in which two areas of light are seen and which, as the mirror is rotated, advance from opposite sides of the pupil and merge into each other. The cause of the phenomena is probably *coma* due to the obliquity of one or more dioptric media of the eye. The medium involved is without doubt, in the majority of cases, the crystalline lens. Monographs by Jackson, Thorington and Sheard discuss practical methods of handling such cases.

166. *Ophthalmoscopy.* We now pass to the applications of the principles of conjugacy of foci to ophthalmoscopy.

The ophthalmoscope is an instrument employed for examining in detail the fundus of the eye through the pupillary opening. A concave mirror similar to that used in retinoscopy may be used as an ophthalmoscope, but when such a mirror is used at the ordinary retinoscopic distance the red fundus reflex only, with no details, is seen. This is due to the fact that the emergent rays seldom have that divergence for which the observer's eye is at that moment adapted, and also to the fact that a very small portion of the retina under

observation is visible at ordinary retinoscopic working distances. In order then to be able to obtain a detailed view of the fundus it is necessary to do one of two things, either (1) approach the eye very close to that of the patient in order to enlarge the field of view, i. e., to carry the fundal image to the observer's distance of distinct vision, or (2) by means of an auxiliary convex lens (in practice a + 13 to + 16 diopter sphere) form a real image of the fundus in the air which can be produced within the observer's range of distinct vision. The first of these affords us the *direct* method of ophthalmoscopy since the image which is viewed is a virtual one, while the second is known as the *indirect* method because the fundus is seen by virtue of the aerial image formed by the auxiliary condenser.

167. The *optical principles* involved in the *direct method* are sketched in Fig. 108. The concave mirror has a focal length of about 3 inches. This is held in such a position with respect to the observed

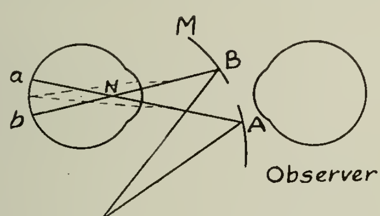


Fig. 108.—Optical Principles Involved in the Direct Method of Ophthalmoscopy.

eye that the light from the source S will be converged to the nodal point N, from which point it will diverge and illuminate an area, ab, of the fundus. The retina then becomes a source of illumination and diffuses the light which emerges from the eye in the manner discussed under *Retinoscopy* as parallel, divergent or convergent beams, depending upon the refractive condition of the observed eye. Hence the distinctness of the image seen by the observer depends upon his own refraction and that of the patient. The observer should be emmetropic, or rendered so by means of his correction, and should likewise be able to suppress all accommodative action at will if he is desirous of using ophthalmoscopic methods to obtain an estimate of the refractive condition of the eye under observation. Suppose, then, that the observer is emmetropic; he can then see the fundus of another emmetrope without any further aid optically, since the rays emerging from the observed eye are parallel and the observer's eye is adjusted for such rays. If the eye being observed is not emmetropic the light emerging from it will be either divergent or convergent; such rays cannot be

brought to a focus on the emmetropic non-accommodated eye of the operator. In the examination of ametropic conditions, therefore, lenses must be revolved into the sight-hole of the mirror—convex in hyperopia and concave in myopia—in order that the emergent light may be rendered parallel and therefore adjusted to the emmetropic observing eye. One, therefore, looks for the strongest convex glass or the weakest concave lens with which he can see the details of the fundus most distinctly; the lens thus turned up before the mirror aperture gives a measure of the refraction of the observed eye. A difference between subjective and ophthalmoscopic refraction generally occurs and this latter method is but little employed in refractive work today.

The chief reasons for these discrepancies are: (1) lack of ability to perfectly relax the accommodation on the part of the observer; (2) distances of the lenses from the observed eye vary considerably between subjective and ophthalmoscopic examinations, hence introduce vital lens differences; (3) the papilla may have a different refraction from that at the macula. The direct method of ophthalmoscopy does, however, furnish a means of judging of the depth of a papillary excavation by a measurement of the difference of refraction between the edge and the bottom of the cup, bearing in mind that a difference of one diopter corresponds to practically one-third of a millimeter. By the same process one can measure the tumefaction of the disc in cases of optic neuritis or estimate the distance from the retina of an opacity in the vitreous body.

168. The *indirect method* in ophthalmoscopy does not give as magnified a view of the fundus as is afforded by the direct method and it is of practically no service in estimating the refraction. The optical principles involved in the indirect method are diagrammed in Fig. 109. The mirror M should have a focal length of about 10 inches. This is used at from 20 to 30 inches from the observed eye close to which a 13 diopter convex lens is held. In the diagram, the reflecting mirror M sends a converging beam of light on L, the condenser, which in turn further converges the light entering the eye. A portion of the fundus, ab, is illuminated. Light returning from any point D emerges and is brought by the lens L to a focus at B from which point it diverges to be focussed on the observer's retina R by the aid of his accommodation or an auxiliary convex lens turned up before the aperture of the mirror. The observer sees, therefore, at B a real inverted image of the fundus magnified about five times.

169. *Size of the ophthalmoscopic images.* (A) *Direct method.* Let us assume for simplicity's sake that the observed and observing eyes are emmetropic and at a distance apart equal to the sum of their

anterior focal lengths so that their focal points coincide at F as shown in Fig. 110. Let OE be a portion of the illuminated retina of the observed eye. Then any ray from E, parallel to the axis, will after refraction pass through F and this point being, in turn, the anterior focus of the observer's eye, this ray will then be refracted parallel to the axis of the observing eye and will reach the retina at a point E_1 such that O_1E_1 is the image of OE. Since the static refractions of the

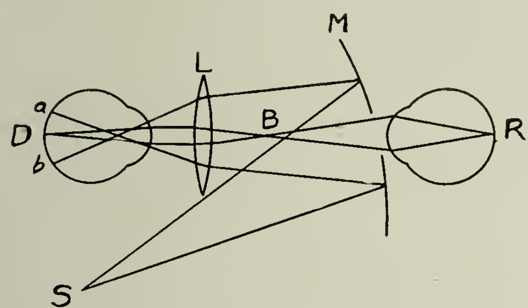


Fig. 109.—Optical Principles Involved in the Indirect Method of Ophthalmoscopy.

eyes involved are equal, then the image (I) received by the observer will be identical with that of the object O. Since the rays issuing from the observed eye are parallel and the observing eye is in a condition to focus upon the retina incident parallel rays, both eyes being assumed emmetropic, the distance between patient and operator is immaterial, hence the size of the image (I) does not alter as the observer approaches or recedes; the only result is a greater or lesser

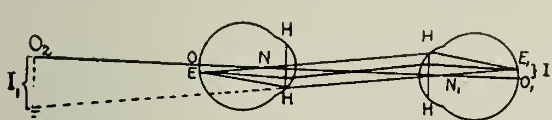


Fig. 110.—Magnification Under Direct Ophthalmoscopy.

field of view. But the observer's retinal image (I) is projected to his distance of most distinct vision and assumes the size of the virtual image diagrammed in the figure as O_2E_2 or, for brevity, indicated as I_1. The distance of distinct vision may be taken as 250 mms. The question as to the ophthalmoscopic magnification becomes, therefore, the following: What is the relation of the visual angle under which the virtual image of the illuminated retinal area (O_2E_2) appears to that visual angle under which the disc itself appears at the distance of distinct vision? The answer is readily obtainable from an inspec-

tion of Fig. 110; for the size of the retinal image I is, under the assumed conditions of emmetropia, equal at all distances of the two eyes to the size of the object OE. The object being viewed through the dioptric apparatus of the eye under examination, the visual angle is equal to $\frac{O_1E_1}{O_1N_1}$. From the similarity of the triangles $O_2N_1E_2$ and $O_1N_1E_1$ it will be seen that the apparent magnification is the ratio of O_2E_2 to O_1E_1 which is equivalent to the ratio of N_1O_2 to N_1O_1. We have, therefore,

$$\text{Magnification} = \frac{I_1}{I} = \frac{N_1O_2}{N_1O_1} = \frac{250}{15} = 17 \text{ (appr.)}$$

It will also be observed that the object O, the retinal image of the

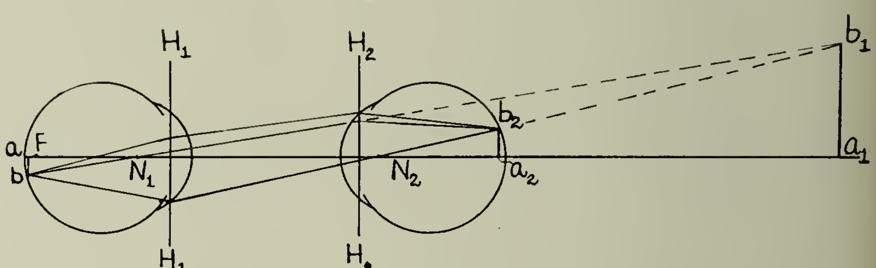


Fig. 111.—Magnification of the Upright Image in an Emmetropic Eye.

observer I and the final projected image I_1 are all formed under the same angle.

As a second case, let the patient's eye be axially myopic by an amount of 5 D. Then the disc lies 1.6 mms. behind the posterior focal point F of the normal eye as indicated in Fig. 111 and the far point a_1 is 200 mms. in front of the principal plane H_1H_1. Let the observer be 40 mms. away from the patient. Under these conditions the hyperopic observer, having a virtual far-point at a_1, sees the object ab at a visual angle given by

$$\frac{a_2b_2}{N_2a_2} = \frac{a_1b_1}{N_2a_1}.$$

The denominator N_2a_1, with the above assumptions, is equal to $200 - 40 - 5 = 155$ mms. if we take the distance of the nodal point N_2

to be 5 mms. from the principal plane H_2H_2. The numerator can be determined (by a pair of equal triangles as shown in the figure) to be $\frac{1.5}{16.6} \times 205$ mms., where 1.5 mms. is the size of the object *ab* and 16.6 mms. represents the depth of the myopic eye from the nodal point N_1 to the retina. The equation then reads $\frac{1.5}{16.6} \times \frac{.205}{155} = \frac{1}{8.3}$.

Since *ab,* at a distance of distinct vision of 250 mms. appears to the observer, without the magnification of the patient's eye, at a visual angle of $\frac{1.5}{255} = \frac{1}{170}$, and since $\frac{1}{8.3}$ is 20.5 times greater than $\frac{1}{170}$, we find the desired magnification to be 20.5.

By a corresponding process it can be shown that the magnification for a case where a patient has a hyperopia of 5 diopters and the eye is 40 mms. distant from the patient is fifteenfold.

If the correcting lens in the ophthalmoscope be situated at F_A, the anterior focal point of the eye under observation, the angle subtended by the image will be the same in hyperopia and myopia as in emmetropia and therefore the magnification will be unchanged; the image is simply sharpened by the correcting lens. Generally, however, the ophthalmoscopic lens is situated beyond the patient's anterior focal point and in that case the angle subtended by the image will be altered in size, becoming larger in myopia and smaller in hyperopia.

170. There are four conditions which influence the size of the ophthalmoscopic field. (a) The size of the observer's pupil must be considered since the greater the pupillary size the greater will be the image on the patient's fundus. As a matter of fact, however, this plays no particularly important part since the aperture in the ophthalmoscope plays the part of the observer's pupil: hence the statement might be made that the size of the ophthalmoscopic aperture must be considered. (b) The distance of the observer from the patient is of great significance because, as the observed eye is approached, the mirror aperture is brought closer and allows a bigger image to be thrown on the patient's fundus. Hence the rule of practical importance that the observer, in the direct method, should approach the patient as close as possible. (c) The size of the patient's pupil is also of great signifi-

cance. It should be dilated as much as possible by shutting off unnecessary light, excluding light from the most sensitive part of the retina or by the use of mydriatics. (d) The position of the point for which the patient's eye is accommodated has a direct bearing upon the size of the field. In the examination of the upright image, the ophthalmoscopic field increases with increasing hyperopia, since the point of accommodation of such an eye is beyond infinity or negative, and in turn decreases with increasing myopia.

171. *(B). Indirect method.* We have already stated that in the in-

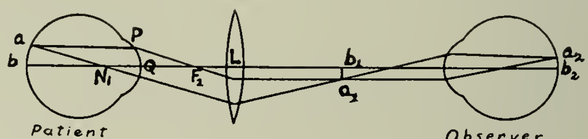


Fig. 112.—Magnification in the Indirect Method of Ophthalmoscopy.

direct method the light emerging from the observed eye is brought to an aerial image by an auxiliary condensing lens, from which image it then diverges to the observer. The observer must, therefore, accommodate for some point between himself and the lens and if his accommodation is insufficient for this purpose he must throw a convex lens into the ophthalmoscopic aperture. In Fig. 112 let ab be a portion of the illuminated fundus, N_1 the nodal point, F_1 the anterior focus of the observed eye, and L the condensing lens. Suppose L to be at a distance from F_1. Then light diverging from a will emerge parallel

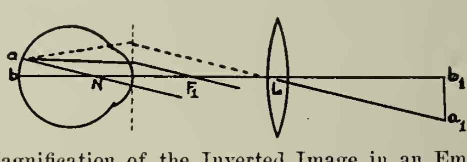


Fig. 113.—Magnification of the Inverted Image in an Emmetropic Eye.

from an emmetropic eye to focus at a_1 in the focal plane of the lens L; b_1a_1 is then the inverted aerial image of the object ab and a_2b_2 is the erect retinal image of the observer secured by accommodating for the plane b_1a_1. The fundus under observation, ab, is therefore seen inverted as b_1a_1. The confines of space in Fig. 112 show a_1b_1 and a_2b_2 smaller or equal to ab; as a matter of fact, each is in practice larger.

Let us determine the size of the indirect image obtained when an emmetropic eye is under examination. Since the light from the observed eye emerges parallel, the ray, such as La_1, Fig. 113, which can pass through the optic center of the lens L must always make the same

angle, b_1La_1, with the axis. Also, the aerial image a_1b_1 must always be formed at the focal distance Lb_1, no matter what the distance of the lens L from F_1. Therefore, as the lens is withdrawn from the emmetropic eye the image must remain the same size. Since the angle aNb equals the angle a_1Lb_1, we have the magnification,

$$M = \frac{b_1a_1}{ba} = \frac{Lb_1}{bN}.$$

But $Lb_1 = 77$ mms., the power of the lens L being generally about $+13$ diopters and $bN = 15$ mms. Hence the magnification, $M = \frac{77}{15}$ $= 5$ (approximately). In emmetropia the optic disc is seen as about 10 mms. in diameter situated at the distance of distinct vision of the observer. The actual size of the observer's retinal image depends upon the angle which the image subtends at his nodal point, so that a person with a close near point, or who uses a convex lens in the ophthalmoscope, secures a relatively larger magnification than one who does not possess these advantages.

172. It can be shown that the aerial image formed by the condensing lens will have the same size in all refractive conditions provided the condenser is at its own focal distance from the anterior focus of the observed eye. If the condenser is withdrawn from the eye variations in size of aerial image will be observed in ametropic conditions. An increase in the size of the image on withdrawal of the condenser denotes myopia and a decrease shows hyperopia.

It is difficult or impossible to see under certain conditions the image of the fundus by the direct method. This difficulty, aside from that arising from pupillary contraction, is usually caused by the excessively high magnification in myopia or to the impossibility of neutralizing the great convergence of the emergent light in high myopia. Similar difficulties do not occur in hyperopia since the high degrees are rare and because the divergent light is easily overcome by a convex lens. Taking, therefore, for illustrative purposes a case of 10 diopters of myopia, we know that its far point is 4 inches away and that the ametropia is correctable by about a -12 D. S. placed at 15 mms. from the cornea. As, however, the ophthalmoscope is rarely held as close as a centimeter or two from the eye, a still more powerful lens would be needed to neutralize the convergency of the emergent light. Thus, if the ophthalmoscope were to be used at 2 inches, it would be

necessary to turn up — 20 diopters in order to get a clear view of the fundus. And again, taking this same case in which the ophthalmoscope is held 2 inches from a myopic eye whose far point is 4 inches, it can be proven that the magnification obtained would be approximately 30 as compared to the ordinarily obtained ratio of 16 — 20 to 1. Hence the field of view would be correspondingly reduced, so that only a very small part of the fundus would be observable without motion of the eye. In a case of 20 diopters of myopia it can easily be seen that if the ophthalmoscope is held at 2 inches from the observed eye (this distance being likewise its punctum remotum) the magnification will be infinitely great and the field infinitely small. If the ophthalmoscope be held 1.5 inch from the eye there would be required about — 80 diopters to give a clear image. This would give a magnification of about 50. No such lens is found in the ophthalmoscope and as a result the instrument must be approached still closer to the observed eye until the power of lens required falls within the range of those supplied. In practice the difficulties experienced in high ametropia are eliminated by putting the approximate correction in a frame as close to the eyes as possible and proceeding as in emmetropia or low ametropias. Normal magnification and normal field of view will then obtain.

PART THREE

QUALITATIVE AND QUANTITATIVE DETERMINATIONS OF THE RETINAL FUNCTIONS

173. There are three principal functions of the retina, to wit:—

1. The sensation of light and darkness or the *light sense*.
2. The sensation of *color*.
3. The perception of *form*.

Each of these three senses can be quantitatively investigated. They are not identical at the macular region and in the peripheral regions of the retina, hence a separate determination of the light, color and form senses must be made in the central and peripheral regions. We shall, therefore, in the study of these topics be concerned with the determination of the so-called threshold values, state of adaptation of the eye, visual acuity, tone, saturation and brightness of color, visual fields and allied topics. It seems, then, desirable at the outset to briefly define certain terms which will be of frequent repetition in this portion of this work and which must of necessity be introduced and used without any previous assurance that there may not be some

overlapping of subject matter in such a manner as to involve correlated topics which may not have been previously discussed.

174. The *field of vision* is the area over which an eye can see indirectly, the visual axis being directed straightforward. The normal field extends, approximately, upwards 50 degrees, downwards 70 degrees, inwards 60 and outwards 80 degrees respectively.

175. The *field of fixation* is the greatest angular distance over which the visual axis can be moved when the head is held stationary and includes the maximum extent of distinct or acute vision. The field of excursion or fixation is normally up 35°, down 55°, in 45° and out 45°.

176. *Visual acuity* is a measure of the ability possessed of receiving, transmitting and mentally interpreting retinal impressions. The transparency of media, the power of the eye, the luminosity under which objects are viewed, the size of the retinal image, the nervous functions of the optic nerve and retina and the mental faculties (i. e., the interpretations of the brain) are factors which influence visual acuity.

177. The *limit distance of vision* is difficult to determine or express; it depends upon the luminosity or the amount of light the object viewed reflects, the clearness of the atmosphere, the color of the object, contrast between object and background, on the elevation of the object and upon whether the object is in motion or not.

178. The *visual threshold* is the lowest limit of light that can be observed by an eye and varies in different people. It is sometimes represented for the normal eye by a piece of white paper feebly illuminated and placed about 600 feet away on a black background.

179. *Illumination* and *visibility* are intimately connected The visibility of an object increases with the luminosity up to a certain point beyond which the intensity of the light becomes dazzling and confusion from internal reflections and consequent blurring of the image occurs.

180. The *adaptation* of the eye relates to the usual phenomena observed when the eye has been exposed to or obscured from light, as for example when a person passes from a bright into a dull light nothing is clearly distinguished at first. This is partially due to previous exhaustion of nervous energy due to stimulation and partly to other causes connected with the visual purple which presumably undergoes a photochemical modification under the influence of light. Or we may say that the visual process requires time to become adapted to different mean brightness levels; the retina requires time to become accustomed to such brightness changes depending upon the magnitude

of the difference between the brightness levels involved and upon the period of time to which it was previously exposed to the first condition.

XV. THE LIGHT SENSE

181. It is probable that the sensation of light is due to the stimulus given to the terminals of the rods, and discrimination between details to the action of light upon the cones. It is known that the cones are much more abundant than the rods at the highly sensitive macula and that, at the fovea, the rods are absent. Furthermore, the foveal and macular cones are smaller then those in the peripheral regions. Toward the ora serrata, where there is practically complete absence of perception of details, the cones are comparatively few in number. Therefore the deduction is made from anatomical data that acute form vision depends upon the cones and light perception upon the rods. The fovea is, in turn, not the most sensitive portion of the retina for feeble illuminants; these are seen better by means of the rods than by the cones.

The range of light wave-lengths with which we are concerned lies within a very narrow range of radiations of less than one octave and is comprised between the limits of 3900 and 7600 Angstroms as the extreme end points.

182. The range of intensity of illumination over which an eye can see with practically equal comfort is enormous, for the average intensity of illumination at noon on a bright day is about a million times greater than the illumination given by a full moon and yet the eye can see fairly well in both cases. *This adaptability to the enormous range of intensity of illumination* which is met with is secured:

(1) By the automatic contraction or opening of the pupil by the muscles of the iris. In low intensity of illumination the pupil is wide open and contracts at higher intensities. The eye has thus a protective mechanism against the entrance of excessive light power, for at high intensity of illumination the pupil of the eye contracts and a sudden exposure to excessive radiation causes the eyelids to close. This mechanism is, however, mainly responsive to long waves of radiation, that is, to the red and yellow light, but not to the shorter waves of blue or violet light. Natural sources of excessive radiation, such as the sun, are rich in red and yellow waves and especially so when this light is received by reflection rather than by direct passage into the eye. The absence of this automatic protective action of the iris and eyelids against light deficient in long waves, as in the mercury lamp, for example, is important because it means that exposure to high intensity of illumination from such sources may be harmful while the same or

even greater *power* of radiations in yellow light would be harmless.

(2) By the fatigue of the retinal processes and nerves when exposed to high intensity of illumination the nerves become less sensitive, while at low intensity they rest and thus become more sensitive, and as a result the differences of sensation are made much less than correspond to the actual differences of radiant intensity.

(3) The impression made upon any of our senses, i. e., hearing, vision and so forth, is not proportional to the energy which produces the sensation but is approximately proportional to its logarithm and hence the sensation changes very much less rapidly than the intensity. Thus, a change of intensity from 1 to 10,000 units is 10,000 times as great a change in intensity as is produced in passing from 1 to 2 units but the change in sensation in the first case, since the logarithm of 10,000 is equal to 4, is only about 12 times as great as the change in the latter case where the logarithm $2 = 0.301$. This leads us to a further discussion of the hypothesis or psychophysical law of Fechner.

183. *Law of Fechner.* The perception of a difference between two luminous areas or sources occurs when the stimulus has attained a definite increase independent of the initial value of that stimulus. According to this law the smallest perceptible difference of illumination is a constant fraction, about 1 per cent., of the total illumination. This is often mathematically expressed as

$$\frac{\delta I}{I} = A$$

in which I represents the brightness and δI indicates the increment of brightness just perceptible; this ratio should be a constant, A. The law or hypothesis of Fechner was designated by him as psychophysical, since it appears to be as generally applicable to other senses as to that of sight as, for example, in the estimates of differences in weights or intensities of sound. The deduction of Fechner's principle is in reality dependent upon the experimentation of Bouguer and of Masson. The experiments of Bouguer as applicable to the principle under discussion are essentially as follows:—Two light sources, A and B, Fig. 114, of equal intensity are employed and an obstacle, C, so situated between these lights and the screen that two shadows a and b are formed on it. The shadow a is formed by A and consequently receives illumination only from B; the shadow b receives, in turn, light only from A. By moving, for instance, A away from the screen, the shadow a becomes weaker and when the distance of A from the screen is nearly ten times that of B it ceases to be visible. We can then

replace the lights A and B by others having only half the intensity and repeat the experiments; it will be found that the shadows cease to be visible at the moment when the distance of A from the screen is about ten times that of B. The same result will follow, to the first order of approximation, whatever may be the intensity of the luminous sources used.

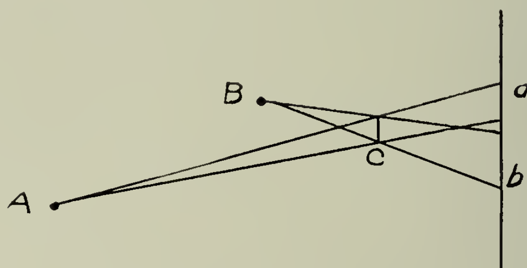


Fig. 114.—Experiment of Bouguer.

From these experiments we may conclude that the differentiable fraction is a constant whatever may be the luminous intensity; that is, $\frac{\delta I}{I} = A$. We know, then, in general that there is a relation between physiological response S and intensity of illumination or luminous stimulation I; that is to say, the value of the differentiable increment δI is a function of I. Hence $S = f(I)$, f being the function of I to be determined. The connection between two infinitesimal changes, δS and δI, is expressible as $\delta S = \frac{df}{dI} \cdot \delta I$. Following the hypothesis of Fechner, then, $\delta S = A$ and $\delta I = \psi(I)$ whence $\frac{df}{dI} = \frac{A}{\psi(I)}$ or

$$S = A \int \frac{dI}{\psi(I)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Bouguer's methods of experimentation established the correctness of

the relation $\frac{\delta I}{I} = B$, or $\psi(I) = B \cdot I$. By a substitution of these in equation (1) given above, we conclude that

$$S = \frac{A}{B}\int \frac{dI}{I} = C \log. I + D \dots\dots\dots\dots (2)$$

If we specify that I_0 shall be the minimum perceptible intensity, or threshold value, then $S = 0$ when $I = I_0$ in the limit, whence $D = -C \log. I_0$, or our complete equation is

$$S = C \log. \frac{I}{I_0} \dots\dots\dots\dots (3)$$

This equation, then, shows the relation between the physiological effect and the physical stimulus or quantity of light.

As a simple illustration of the verification of the ratio $\frac{\delta I}{I} = A$ by Bouguer's experiments, we will suppose that when the shadow disappears *A*, Fig. 114, is 500 cms. and *B* 50 cms. from the screen. The illumination is, of course, proportional to the intensity of the luminous source and inversely proportional to the squares of the distances. *B* therefore gives to the screen an illumination of $\frac{1}{(50)^2}$, *A* an illumination of $\frac{1}{(500)^2}$, while the shadow *a* receives an illumination of $\frac{1}{(50)^2}$. The difference between the illumination of the screen and that of the shadow is, therefore,

$$\left(\frac{1}{50^2} + \frac{1}{500^2}\right) - \frac{1}{50^2} = \frac{1}{500^2} = \delta I.$$

The ratio $\frac{\delta I}{I}$ then becomes

$$\frac{\dfrac{1}{500^2}}{\dfrac{1}{50^2}+\dfrac{1}{500^2}} = \frac{1}{100+1} = \frac{1}{101} = A$$

As a second case, when the intensity of light sources is only half as great, we find that

$$\frac{\delta I}{I} = \frac{\dfrac{\frac{1}{2}I}{500^2}}{\dfrac{\frac{1}{2}I}{50^2}+\dfrac{\frac{1}{2}I}{500^2}} = \frac{1}{101} = A$$

This law of Fechner explains many of the phenomena of daily observation. One reads nearly as well in the evening under gas or electric light as in daylight, although the illumination in daylight is much greater, because the ratio between the light reflected by the black letters and that reflected by the white paper remains the same.

184. But the *law of Fechner* is true only for *medium degrees of illumination.* The sensibility of the eye to brightness differences is greatest over a wide range of intensities but falls off at very low or very high luminosities. Within the ordinary limits of illumination used in everyday life we may say that the law of Fechner is verified with considerable exactitude. These departures from this law have been investigated by a number of experimenters. The classic experiments are those of Masson, Charpentier and of Koenig and Brodhun. The photoptometer of Charpentier may be used as a differential instrument and is of particular service in very low intensities. The photoptometer, *per se,* consists of a tube about 22 cms. long and 5 cms. wide, the extremities of which are closed by plates of ground glass *A* and *B*. At the middle of the tube are placed two lenses of 11 cms. focal length and between them a diaphragm of changeable aperture. On illuminating *A* the lenses project an image of it on plate *B;* the brightness of this image may be made to change by altering the aperture of the diaphragm. It is the plate *B* which serves for observation; the minimum aperture of the diaphragm which permits the observer to distinguish the plate *B* determines the threshold. A

modified form of the instrument, known as the differential photoptometer and which is particularly serviceable when the intensities are feeble and for the determination of $\frac{\delta I}{I}$, consists of two photoptometers at right angles to each other and each making an angle of 45° with a glass plate placed in the center of the long tube containing the first photoptometer and the sighting tube. The instrument is assembled in a manner analogous to the first ophthalmoscope of Helmholtz.

185. Another method of determining the smallest perceptible difference is due to Masson and depends upon the principle of persistence of vision. The disc of Masson is a white one in which different sectors of varying sizes have been blackened as shown in Fig. 115. By causing a sufficiently rapid rotation of this disc one can see three

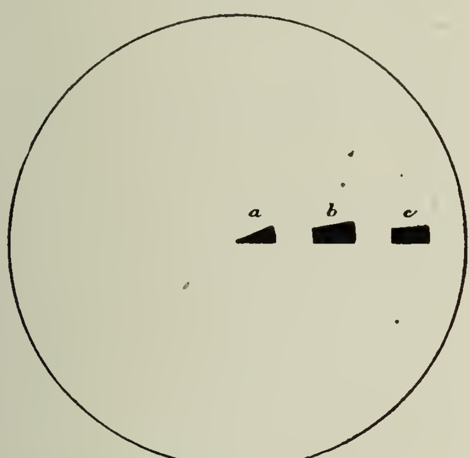


Fig. 115.—Disc of Masson.

gray rings separated by white intervals. Supposing the sector *a* is 20° and the sectors *b* and *c* to be 10° and 5° respectively, and further assuming that the black areas do not reflect any light at all, the brightnesses of the three gray rings will be 340, 350 and 355 if we consider the light of the solid white rings as 360. The difference between the extreme gray rings and the white will be 5 and the relation $\frac{\delta I}{I}$ will then be equal to $\frac{5}{360} = \frac{1}{72}$ which represents the value of

Fechner's fraction for the patient under examination if he can distinguish the three images. If he can distinguish only two, Fechner's fraction becomes $\frac{360 - 350}{360} = \frac{1}{36}$. A large number of sectors is used in such experimentation; good illumination must be employed and the patient must not be too remote in order that the influence of diminished visual acuity (because of distance) may not enter into the problem.

186. A simple modification of this rotating disc, made by Masson, consists in drawing upon a white disc a series of equal black and white apertures running in a straight line from the center of the disc to the periphery as shown in Fig. 116. Upon rotation the black lines form gray bands which vary in distinctness as the center is approached.

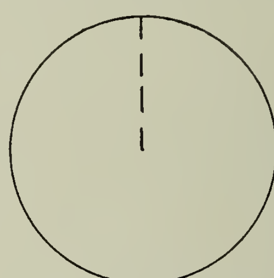


Fig. 116.—Modification of Disc of Masson.

In order to determine the minimum perceptible difference one must count the gray and white rings, produced by the rotation of the disc, proceeding from the center to the circumference. The distance which separates the center of the disc from the black mark which forms upon rotation the last discernible gray circular ring is proportional to the light sense of the subject examined. The value of the minimum differential can thus be obtained as a fractional part of the brightness of the white disc; if d is the width of the black rings, i. e., the size of the black interruptions on the disc as represented in Fig. 116, and r is the radius of the last discernible gray ring, when the disc is rotated, measured from the center of the disc, and if the intensity of the white portions of the disc is taken as unity, then the intensity h of a gray band during rotation is given by the expression

$$h = 1 - \frac{d}{2\pi r}.$$

The minimum perceptible difference, δ, is by definition equal to $1 - h$ and hence we have

$$\delta = 1 - \left(1 - \frac{d}{2\pi r}\right) = \frac{d}{2\pi r}.$$

These and other methods of investigation have shown that Fechner's constant varies when the intensities of illumination are very

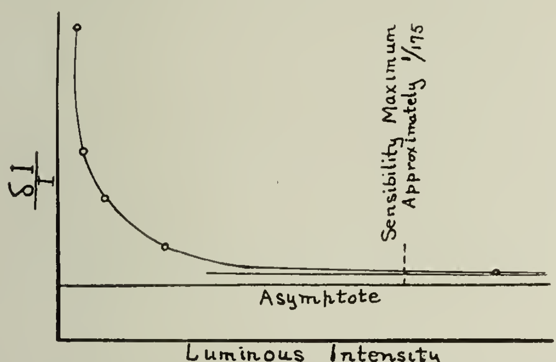


Fig. 117.—Curve Obtained by Broca Illustrating Change of $\frac{\delta I}{I}$ with Luminous Intensities.

high or low. Aubert, following the methods of Bouguer, obtained the following values, the light intensities being expressed in meter-candles:—

Illumination (Meter-Candles)	*Sensibility*
17.7	$\frac{1}{164}$
4.3	$\frac{1}{140}$
2.5	$\frac{1}{123}$
1.1	$\frac{1}{106}$
0.9	$\frac{1}{104}$
0.4	$\frac{1}{94}$
0.2	$\frac{1}{90}$
0.1	$\frac{1}{67}$
0.025	$\frac{1}{35}$

A repetition of similar experiments by Broca using the rotating disc of Masson gave the curve exhibited in Fig. 117, showing that $\frac{\delta I}{I}$ changes rapidly under low intensities.

187. The acuity of the light sense may be very properly expressed as the reciprocal or inverse of Fechner's fraction. If, for example, the latter be $\frac{1}{150}$ we may say that the acuity of the luminous sense is equal to 150 or if, by diminishing the illumination, the fraction increases to $\frac{1}{50}$, we have a luminous acuity of only 50.

We can represent the relation between the light sense and the illumination by a curve which has the form shown in Fig. 118. This has been done by Tscherning and has the following significance. The horizontal line represents the amount of illumination beginning with complete darkness to the left of the point a and terminating on the

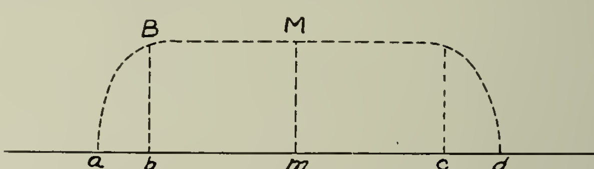


Fig. 118.—Curve Showing the Relation Between the Light Sense and Illumination.

right at the point d representing the direct illumination due to the sun with its dazzling effects. The ordinates represent the acuity of the light sense. When the illumination is very weak the eye sees nothing; when it reaches a certain degree, represented in the diagram by a, the eye begins to be able to distinguish white objects. The degree of illumination which forms the lowest limit of visibility is called the *threshold*. From this point on the light acuity increases rapidly and when the illumination has reached a certain degree, b, the acuity reaches the value which it holds over a considerable range of luminous intensities. *Fechner's law* is true for the range from b to c. Experimentation has shown that the value of $\frac{\delta I}{I}$ for white light becomes a constant when the luminosity has reached a value of approximately one lumen per square foot.

188. *The threshold.* We have discussed at some length Fechner's law relative to the sensibility of the retina to brightness differences;

there remains still to be considered the determination of threshold values. The threshold may be readily determined by the photoptometer of Foerster shown in Fig. 119, *A* and *B*. This instrument, in essentials, is a box carrying at the rear end a whitened surface, *T*, on which are painted large black stripes. The eyes observe these through two apertures a and a_1 (see Fig. 119, A). The light which penetrates

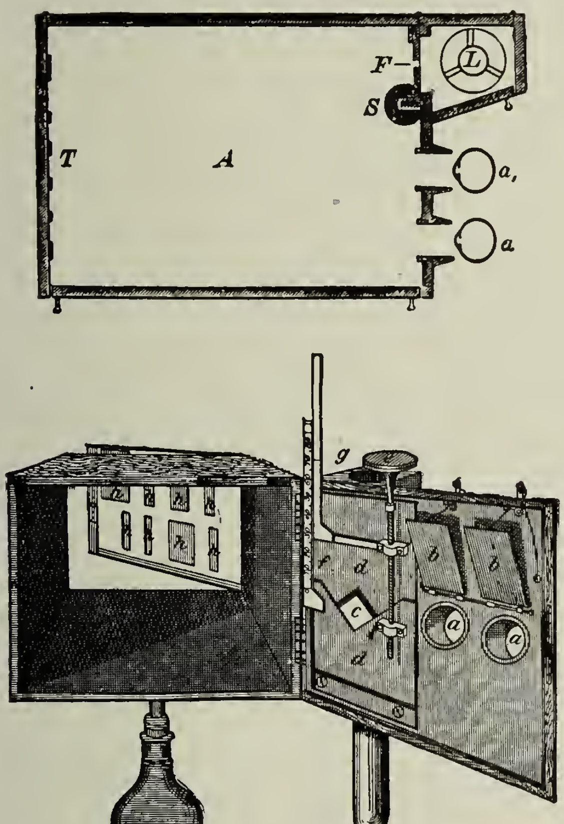


Fig. 119.—Diagrams of the Photoptometer of Foerster.

into the box comes through a window *F*, the aperture of which can be changed. Inside the compartment, screened off by the window *F*, is a standard candle *L*. The minimum aperture of the window *F*, which of course regulates the amount of illumination falling upon *T*, permitting the observer to see the black marks gives the threshold value. The results are subject to the variations which arise from various conditions of retinal adaptation.

189. Aubert determined the threshold of the normal eye; he found that the weakest light that can be distinguished is that of a sheet of white paper illuminated by a candle placed at a distance of from 200 to 250 meters. But the luminous sense varies within wide limits with the state of the retinal adaptation; it is indispensable, therefore, that the state of the adaptation be known in determining the light sense. In fact a determination of the threshold values made after various periods of the exclusion of light from the eye may be said to constitute a means of determining the retinal adaptation. Experiments by Charpentier and others have shown that the minimum perceptible intensity of light diminishes rapidly during the first ten minutes of seclusion in darkness and that after twenty-five minutes this has ordinarily reached a minimum which varies but slightly; the retinal sensibility has, therefore, reached its maximum practically. This means that the subject under examination must be kept in darkness, with eyes bandaged, for at least twenty minutes before determining the threshold values. Charpentier made determinations on the retinal sensibility under different conditions of adaptation and illumination. These latter tests were readily carried out by using as absorbing screens various thicknesses or deeper shades of smoked glasses. Some of the results are tabulated below:—

State of the Eye	*Fraction of light traversing glass plate*	*Sensibility*
Adapted for darkness	0	1000
Adapted for Glass No. 1.......	0.154	40
Adapted for Glass No. 2.......	0.413	17.85
Adapted for Glass No. 4.......	0.617	12.36
Adapted for ordinary daylight..	1.000	4.44

Charpentier observed that the ratio of the sensibilities between an eye adapted for strong light and for darkness was about 1 to 2500.

200. For a weak illumination the light sense of the *macula* is less acute than that of the surrounding parts. By fixing a point a little to one side of the fovea one can distinguish more readily the brightness of objects which differ but little from the background as, for example, when one tries to differentiate very dim stars from their settings. Parinaud and other writers have attributed this phenomenon to the fact that the fovea does not possess the faculty of being able to adapt itself to very weak illuminations as other portions of the retina because the fovea, composed of cones, has no retinal purple. This *retinal purple* has been considered by many as the source of the

adaptation. This hypothesis receives some confirmation from the fact that the time of repose required by an eye to reach complete adaptation is nearly the same as that which is necessary for the reproduction of the visual purple. But the blue rays play a dominant part in vision by weak illumination and it is possible that the inferiority of the macula may be due to its yellow pigmentation which absorbs, in part at least, the shorter wave-length energy incident upon it.

201. In certain pathological conditions the threshold values are affected. In *hemeralopia* the threshold is displaced upwards; it is probable, however, that this is an anomaly dependent rather upon the longer time demanded than in standard or normal conditions for complete adaptation. The existence of hemeralopia may be proven by the photoptometer of Foerster or by an examination of the visual acuity under reduced illumination. Then again there are those who see better when the illumination is low. By comparison of patients having *nyctalopia* with normal persons it is found that the lessening of the illumination causes the acuity of the normal individual to diminish more rapidly than in cases of nyctalopia. The fraction of Fechner is sometimes increased in consequence of which patients do not distinguish gray from white. This may be met with in cases of optic atrophy and in central scotoma. "One of the first cases of this kind was observed at the clinic of Hansen Grut, at Copenhagen, and described by Krenchel. It was a person who presented himself, saying that he did not see well enough to find his way. Examined with the ophthalmoscope, the papillæ were whitish, the visual acuity was normal and the visual field was only slightly contracted. It was puzzling, therefore, to explain the complaints of the patient until the idea of examining him with the disc of Masson presented itself: the fraction of Fechner had increased to 1/10. The patient distinguished perfectly black on white, but was unable to distinguish between gray shades, as they present themselves, for example, in street paving; whence the difficulty which he experienced finding his way." (Tscherning—translation by Weiland.)

202. *The light sense using colors.* The whole of the discussion and data upon the light sense thus far presented have been devoted to brightness differences and threshold values when white light has been employed. The least perceptible brightness increment varies for lights of various colors; we shall treat of these phenomena under the present caption rather than to defer them to the division devoted to the color-sense. In the first place, Purkinje observed that colored papers placed in a chamber in which the illumination falling upon them could be varied were seen first of all without color sensation. Charpen-

tier investigated these phenomena of Purkinje with his photoptometer employing "dark adapted" eyes. He used pure spectral colors and found that the sensation of light only without color sensation was evidenced first and that by increasing the size of the diaphragm and hence increasing the illumination a consciousness of color followed. He differentiated, therefore, between *color minimum* and *light minimum* and specified as the *photochromatic interval* the ratio of the two intensities necessary to produce the sensations of light and color. Charpentier's observations with an eye adapted for darkness showed that the ratio of the apertures permitting light sensation and color sensation varied greatly with the kind of light. His results are as follows:

Color	*Ratio of Apertures*
Red	3.6 to 4
Orange	5.5
Yellow	9.6
Green (average)	196
Blue (French)	625

The methods of procedure in studying the variations of the light-sense using colored stimuli are precisely the same as those used with white light. We are interested, then, in determining the variations in Fechner's law, the threshold values and the effects of the retinal adaptation for various colors and light intensities. The following table gives the data of chief interest to us: for each intensity the unit chosen has been the minimum perceptible brightness for each color after the eye has been obscured in darkness for twenty-five minutes.

Values of $\frac{\delta I}{I}$

Luminous Intensity	Red	Yellow	Green	Blue
6.5 units	0.64	....	....	....
25	0.30	0.36	1.2	1.45
56	0.16	....	....	....
100	0.105	0.20	0.49	0.90
225	0.11	0.14	0.28	0.69
400		0.09	0.25	0.48
900		0.068	0.16	0.36

203. These results are plotted in Fig. 120; one sees, with the unit of luminous intensity chosen, that the curves are very different. But this is no longer the case if one takes as the basis the threshold values of the color sensation, that is the chromatic minimum, rather than the minimum light-sense values. For the photochromatic interval increases from the red toward the violet; the result will be that one will obtain the same curve for all colors within the limits of light intensities commonly employed. Hence the differential sensibility is the same for

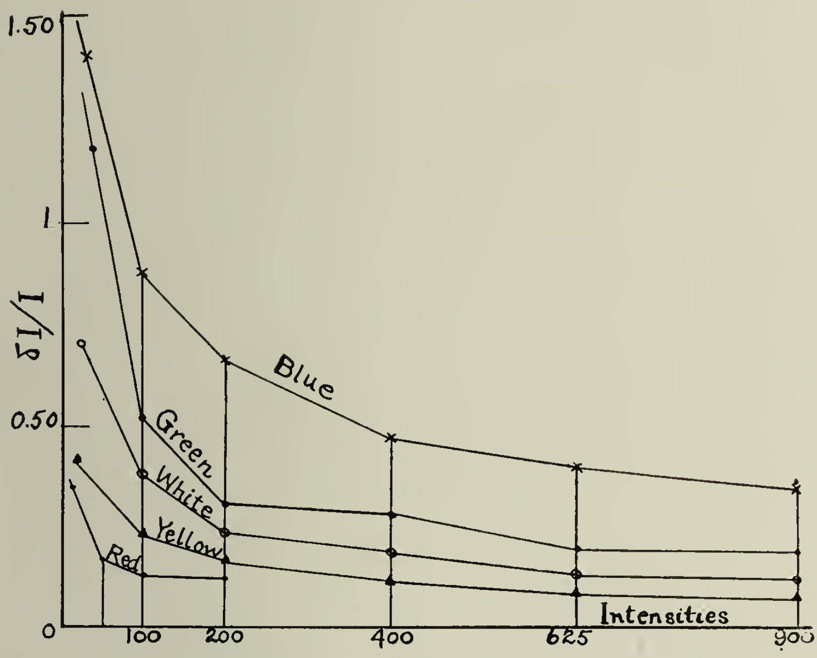


Fig. 120.—Curves Illustrating the Light Sense with Various Colors and Intensities. (After Charpentier.)

all the colors when one compares them under equal intensities, the unit being defined for each of them by its chromatic minimum. With decreasing luminous intensities the sensibility diminishes more rapidly for waves of longer length than for those of shorter length. Koenig and Brodhun have carried out an elaborate series of experiments in this field. They determined the least perceptible brightness increment for lights of various colors, including white, for brightness of a neutral tint (white) surface illuminated to intensities varying from 1,000,000 meter-candles to nearly the threshold of vision using an artificial pupil of 1 square millimeter area.

204. The essential features of a spectrophotometer similar to that employed by Koenig and Brodhun and diagrammed in Fig. 121 are fundamentally as follows: In front of the lens *B* of the collimator is placed a double image prism, *C*, which consists of a prism of calcite or quartz cut with its refracting edge parallel to the optic axis of the crystal cemented to a second prism of equal angle made of the same material but cut with the refracting edge perpendicular to the optic axis. A ray of light *I*, Fig. 121 (b), will pass through the prism *ABC*, in which the refracting edge is perpendicular to the optic axis, parallel to this axis and hence the ordinary and extraordinary rays will coincide in direction. On reaching the prism *ACD*, in which the

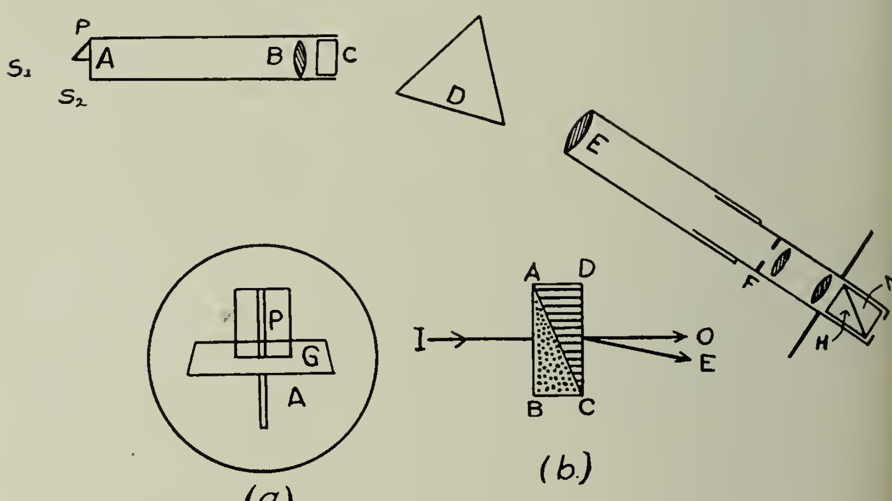


Fig. 121.—Optical Principles of a Spectro-Photometer.

refracting edge is parallel to the optic axis, the ordinary ray, *O*, will be undeviated, while the extraordinary ray, *E*, will be deviated. Hence the ordinary and extraordinary rays will proceed in directions inclined at a small angle. Thus the incident unpolarized light is divided by its passage through the prism into two rays of equal intensity which are plane polarized, the planes of polarization being at right angles. The double image prism is placed in front of the collimator object glass, and on turning the observing telescope to view the slit, the prism *D* having been removed, two images of the slit will be seen. The double image prism is then rotated until these two images form a single line. The two images overlap in the center; a piece of paper, *G*, Fig. 121 (a), must be pasted over the central portion of the slit and its width adjusted so that, of the four images now formed, the two middle ones just touch but do not overlap. Thus in the center

of the field there will be two adjacent images of the slit, one formed by the light which has passed through the upper portion of the slit and the other by light which has passed through its lower portion and these will be prolonged in planes at right angles to each other. The Nicol, N, with its divided circle, is attached to the telescope and turned until one of the images vanishes, when the reading on the circle is noted. This gives the zero reading; rotation of the Nicol through 90° from this position will cause the other image to vanish. On placing the prism D on the table two spectra will be seen, one formed with light from each half of the slit. Suppose, then, that the lower half of the slit is illuminated by a source of light S_1, while by means of a totally reflecting prism P, the light from a second source S_2 is caused to illuminate the upper portion of the slit; the two spectra will then be due to the two light sources. To compare the brightness for different color values a diaphragm F, with a narrow vertical slit, is placed at the focal plane of the eye-piece of the telescope so as to cut out all of the spectrum except the portions which are to be compared. The Nicol is then turned until the two portions of the spectra appear equally bright. Let the angle through which the Nicol has been turned from its zero position be θ. Then

$$\frac{I_2}{I_1} = \tan^2 \theta,$$

where I_1 and I_2 are the intensities of the two sources of light of the wave-lengths under consideration and comparison. This instrument may be used for comparisons of light sources, for plotting the relative richness or deficiency of a given source in comparison with a standard for various spectral regions and also for the investigations of Fechner's law.

205. Koenig and Brodhun started at 600 meter-candles and extended the illumination above and below by the various steps indicated in the subjoined table. The data for Koenig's eye, after modification by Nutting, are shown in the accompanying table and in Fig. 122, in which the logarithm of the illumination I is plotted against the maximum perceptible brightness increment $\frac{\delta I}{I}$. It appears that the increment of brightness difference just perceptible increases as the brightness decreases and more rapidly for rays of longer wave-lengths. At high illuminations the minimum perceptible increment is about the same, 1.6 per cent., for all colors including white. It will be seen that when the illumination reaches 60 meter-candles the curves for different

wave-lengths merge into one curve. In the table, I_0 represents the threshold value of brightness measured as a fraction of the standard light brightness. The data of Koenig and Brodhun has been extended by Nutting by computation to the point where $\frac{\delta B}{B}$ (where B represents brightness) $= \frac{\delta I}{I} = 1$; that is, the threshold value.

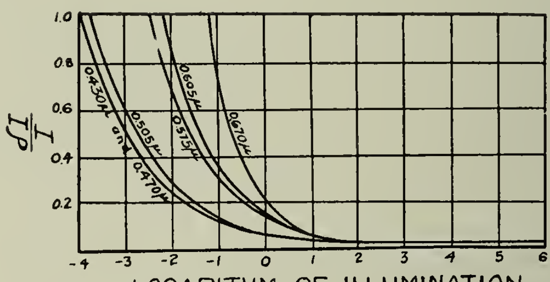


Fig. 122.—Curve Showing Relation of the Logarithm of the Illumination Plotted Against the Minimum Perceptible Brightness Increment.

Table of Data of Koenig and Brodhun on Brightness Sensibility as Recalculated by Nutting

Wave-length I_0	0.670μ 0.060	0.605μ 0.0056	0.575μ 0.0029	0.505μ 0.00017	0.470μ 0.00012	0.430μ 0.00012
Meter Candles			$\frac{\delta I}{I}$			
200,000.000	......	0.0425	......	......	......	......
100,000.000	......	0.0241	0.0325	......	......	......
50,000.000	0.0210	0.0255	0.0260	......	......	......
20,000.000	0.0160	0.0183	0.0205	0.0195	......	......
10,000.000	0.0156	0.0163	0.0179	0.0181	......	......
5,000.000	0.0176	0.0158	0.0166	0.0160	......	......
2,000.000	0.0165	0.0180	0.0180	0.0175	0.0180	......
1,000.000	0.0169	0.0198	0.0185	0.0184	0.0167	0.0178
500.000	0.0202	0.0235	0.0180	0.0194	0.0184	0.0214
200.000	0.0220	0.0225	0.0225	0.0220	0.0215	0.0245
100.000	0.0292	0.0278	0.0269	0.0244	0.0225	0.0246
50.000	0.0376	0.0378	0.0320	0.0252	0.0250	0.0272
20.000	0.0445	0.0460	0.0385	0.0295	0.0320	0.0345
10.000	0.0655	0.0610	0.0582	0.0362	0.0372	0.0396
5.000	0.0918	0.103	0.0888	0.0488	0.0464	0.0494
2.000	0.1710	0.167	0.136	0.0655	0.0715	0.0600
1.000	0.258	0.212	0.170	0.0804	0.0881	0.0740
0.5	0.376	0.276	0.208	0.0910	0.096	0.0966
0.2	......	0.332	0.268	0.110	0.127	0.116
0.10	......	......	......	0.133	0.138	0.137
0.05	......	......	......	0.183	0.185	0.154
0.02	......	......	......	0.251	0.209	0.223
0.01	......	......	......	0.271	0.189	0.249
0.005	......	......	......	0.325	0.300	0.312
0.002	......	......	......	......	......	0.369

206. The value of the minimum perceptible increment depends upon the method of making the measurements. Usually the brightness of one of the two parts of the photometric field is varied until it appears just perceptibly brighter or darker than the comparison field. The brightness of one portion of the field is varied between certain limits for which it is respectively brighter and darker than the comparison field and these limits are gradually brought nearer together until the middle point is estimated as accurately as possible. P. W. Cobb has recently obtained minimum perceptible increments for white light of less than one-half a per cent. and has come to the conclusion that this increment has a smaller value than that obtained by Koenig and Brodhun.

Charpentier investigated the variations of the photochromatic interval with the retinal adaptation and arrived at the conclusion that, when the eye was fatigued in each case by white light, the chromatic minimum was not modified but that the luminosity minimum decreased in proportions analogous to those which have been observed with white light. The adaptation, then, has essentially to do with the light sense and very little with color-sensation.

207. If one attempts to compare *lights of different colors,* the eye manifests an indecision and uncertainty in its determination of equal brightnesses. For a difficulty is encountered in what is known as the *phenomenon of Purkinje.* If we equalize two sources, one of which is red and the other blue, and then diminish their brightnesses one-half, the blue light will appear much brighter than the red light. As an illustration,—if two papers are selected, one of which is red and the other blue and which by daylight appear to have the same brightness, then by diminishing the illumination the blue will appear brighter than the red paper. In very feeble illumination the red paper will appear black and the blue a pale gray. The papers must be viewed at an angle which is not too small since the phenomenon is not so pronounced for the macula. Likewise Macé de Lépinay and Nicati have shown that the visual acuity falls off much more quickly on diminishing the illumination when red light is used than under blue light. If we select red and blue glasses such that the acuity is the same when viewing the chart by daylight illumination, it will be found that, by reducing the illumination by shutters or curtains, the blue glass permits of the reading of the chart while with the red glass the chart cannot be seen at first; after a little time the larger letters only are readable through the red glass. Hence the acuity through the red is much inferior to that through the blue glass; the latter remains practically stationary.

208. The following experiment, quoted from Tscherning, shows in a striking manner the difference which exists in this respect between the two extremities of the spectrum. "We project the spectrum on the screen *A* pierced by two apertures, allowing the red rays and the blue and violet rays to pass. Behind the screen *A* we place a lens which re-unites these rays on a second screen *B*, forming on it an image of the surface of the prism which is turned toward *A*. This image then shows a pretty purple color. In front of the screen *B* we place a stick which forms thereon two shadows, one red, the other blue, and it is easy to so regulate the apertures of the screen *A* that both shadows may have the same brightness. If we now diminish the width of the slit through which light reaches the prism the purple is diluted more and more with white. The blue shadow becomes grayish and brighter and brighter as compared with the background, while the red shadow retains its color but becomes darker and darker. Finally it is nearly black and alone visible, the other shadow being gray and having nearly the same brightness as the background."

209. The yellow and green rays are in the regions of greatest visual brightness in the ordinary continuous spectrum. This brightness diminishes toward the two extremities of the spectrum but less toward the red than toward the blue end. This difference in the two extremes of the spectrum is largely due to the fact that the prismatic dispersion is greater as the wave-lengths decrease and hence the blue and violet are spread over a much greater space than the colors of greater wave lengths. For if the spectrum is produced by means of a diffraction grating, in which the dispersion is uniform for all colors, it will be found that the intensity is greatest in the middle of the spectrum and diminishes almost equally toward the two extremities. Lessening the intensity of the luminous source causes the spectral colors to change hue. The yellow and blue are the first to disappear; the red, green and violet only remain and these take the places of those which have disappeared. By a further reduction in intensity the blue changes into a blue-gray, the green into a grayish-green, the red becomes brownish. Finally, on still further reducing the luminosity all the colors disappear and only gray remains. It is stated that red alone forms an exception to this statement; it does not appear to change into gray before disappearing. The colors, then, disappear when the luminosity becomes sufficiently feeble; likewise, in turn, when the brightness becomes too strong or rather excessive the impression approaches white. The sun viewed through a red glass allows only red rays to pass through and yet the sun appears of a yellowish-white color. By first passing sunlight through a blue filter and then con-

centrating the light on a screen by means of a lens the image of the sun will be found to be white. A spectrum of sunlight produced by turning a prism toward the sun will be seen as a colorless strip of extreme brightness. According to Parinaud all these phenomena depend upon the adaptation of the eye. The spectrum of feeble bright-

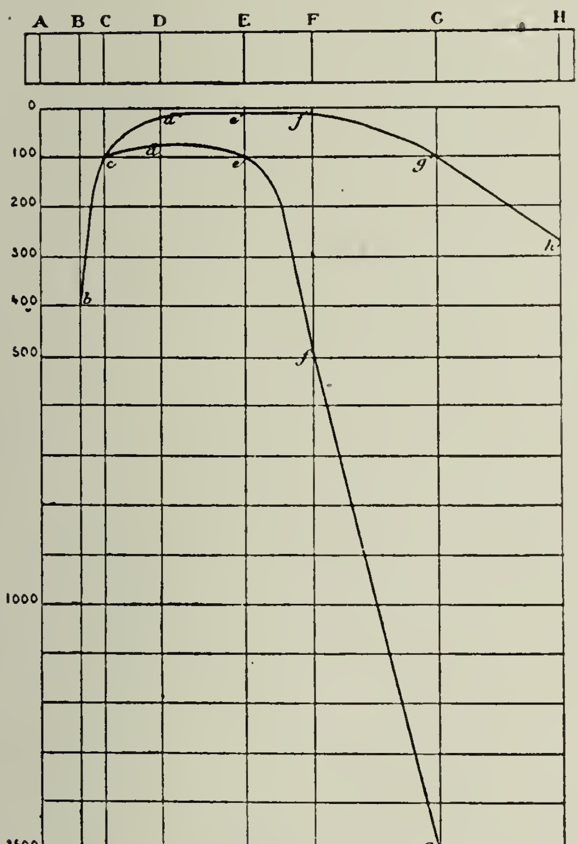


Fig. 123.—Illustrative of the Phenomena Dependent on the Variation of the Brightness of Illumination and Adaptation of the Eye. (After Parinaud.)

ness which appears gray to the adapted eye is invisible to the non-adapted eye. When the intensity increases it becomes visible to the non-adapted eye and appears colored. Parinaud determined the threshold values for different rays of the spectrum and obtained the curves shown in Fig. 123. The upper curve is for the adapted eye, while the lower curve represents the non-adapted condition. The letters *A, B, C* and so forth refer to prominent Fraunhofer lines and

indicate roughly the division of the spectrum into the ordinarily named six or seven colors. The ordinates indicate the quantities of light necessary in order that these different parts of the spectrum may be seen. The curves show that the adapted eye requires a quantity of light equal to unity (this quantity being taken as a standard) in order to perceive the green rays in the region E, while the non-adapted eye requires a quantity equal to 100 in order to perceive the same rays. Again, in the blue at G the adapted eye requires 100 units and the non-adapted eye about 1,500 units in order to perceive them. The two curves by comparison show, therefore, that an eye gains nothing for the perception of red by adaptation but that it gains greatly for the colors of shorter wave-lengths. It gains in luminosity sensibility only, since, with the exception of the part bc which is common to both curves, the whole of the upper curve corresponds to colorless sensations only. The fovea apparently gains nothing by adaptation; the rays give color sensation at the same brightness as they evoke light sensations. These results of Parinaud have been criticized by Charpentier according to whom it is incorrect to attribute the colorless sensations which the rays of weak luminosity call forth to the retinal adaptation. However, retinal adaptation must play some rôle in these phenomena. Charpentier gives the following interesting observations. He covered one of the plates of his photoptometer with a black paper pierced by seven small openings in a space of nine millimeters square. The other plate was illuminated by light from different portions of the spectrum. On gradually opening the diaphragm of the instrument he demonstrated that the first impression which is obtained is that of a diffuse luminous area and colorless; let us specify the size diaphragm under these conditions by the symbol "x." In order to distinguish the color it was necessary to increase the aperture to a value, let us say, of "y." Only by still further increasing the diaphragm to a size "z" was it found possible to distinguish the points; in other words, the order of phenomena was *light-*, *color-* and finally *form-sense.* On the other hand, for an eye adapted to darkness, the apertures "y" and "z" remained about the same as for the non-adapted eye, but the aperture "x" could be diminished greatly for the more refrangible rays, demonstrating that the retinal adaptation is an important factor in the sensation of light but that it plays a minor part in color sensation.

210. *The luminosity curves of the eye.* The sensitivity of the eye to radiation obviously changes with the frequency, as it is zero in the infra-red and in the ultra-violet in which regions the radiation is not visible. The sensitivity gradually increases from zero at the red end

of the spectrum to a maximum somewhere near the middle of the visible spectrum and then decreases to zero at the violet end; that is, the physiological effect produced by the same radiation power—as, for example, one watt of radiating power—is a maximum near the middle of the visual spectrum. Inversely, it may be stated, the *mechanical equivalent of light,* or the power necessary to produce the same physiological effect, is a minimum near the middle of the spectrum and increases from there on to infinity at the ends of the spectrum where no power of radiation can produce visibility. It would appear, therefore, that the power equivalent of light is not a constant like the mechanical equivalent of heat but that it is a function of the frequency, or in other words of the color, and that its maximum is not far from 0.01 watt per candle power in the middle of the spectrum.

211. Various methods have been employed for the determination of the sensitivity or luminosity curves of the eyes and various experimenters are not yet in accord in the results which they have obtained nor in the elimination of sources of error and points of dispute in their methods. Obviously, direct comparison photometric methods are open to the objection that one cannot accurately compare lights of different color since the photometer compares by *identity,* and lights of different color cannot be made identical. And yet the spectral luminosity curve may be obtained by this method if it is modified by the so-called "cascade" procedure. This method involves a comparison of luminosities by introducing slight hue differences since, if the color difference is small, direct comparison can be made with fair accuracy. The essential point in the method is, then, the comparison of yellow with red, let us say, through several transition steps of small value between these limits. The liability to error in this method is obvious; the more steps there are the less likely perceptible differences in color will arise between steps and the less the errors would appear to be, but in the end it is the summation of percentages of errors which must be taken into account. Another method and one which is in greatest favor at present consists in the use of a *flicker photometer;* this instrument has been fruitful of results in the hands of Nutting and of Ives in particular in the last ten years. In its simplest form it consists of a stationary disc, illuminated by a lamp and a rotating half disc or sector in front of it illuminated by another lamp. At slow rotation a flicker is observable but this disappears if the speed becomes high enough. It is apparent that the more nearly equal the effects of the two illuminants under consideration—that of the stationary disc and of the rotating sector—the lower will be the speed at

which the flicker disappears and hence, by an adjustment of the distances of the two lamps so as to cause the flicker to disappear at the minimum speed, the instrument shows equality of the effect of the two successive illuminations on the eye. Whether these flicker methods give wholly reliable data is a question; the persistence of vision and the general physiological effects of different colors are different and we may therefore postulate a *mixture effect* of such a nature as to be forced to admit that we are not comparing lights of different color values by their illuminating values but by some other feature (this word is used for want of a better term) not directly related to the phenomena.

And, again, another instrument for the determination of sensibilities is the *luminometer,* a very simple device consisting of a black box to screen off extraneous light and carrying an aperture to allow only the light of the source under investigation to fall upon a white card printed in black, the reading matter consisting of a jumble of small letters, capitals and so forth arranged in meaningless order. The method of using it depends upon acuity tests; the observer moves toward or away from the light until a point is found at which the large letters can be clearly distinguished, the small letters remaining indistinguishable. It is claimed by many that this point can be found with considerable sharpness, and that, therefore, the luminometer gives consistent and reliable readings with widely different colors of light. But the error in this method is obvious; any comparisons dependent upon acuity are subject to much uncertainty.

212. In view of these facts we shall content ourselves with the giving of a description of one of the classic methods employed by Abney who used an apparatus of the form schematically shown in Fig. 124. The light from the slit S_1, which is placed at the principal focus of the first lens L_1, falls as a parallel beam of light on the prism P. After refraction parallel rays of each of the different colors fall on the lens L_2 and are brought to a focus on the screen DD. In the screen there is a second slit S_2 through which rays of only one refrangibility pass. These rays fall on a third lens L_3 arranged so as to produce on a white screen at FE an image of the nearer face of the prism. By moving the slit S_2 a patch of light of any required color can be thrown on the screen at FE. Slight tiltings of the lenses L_2 and L_3 must be given in order that a sharp image of the whole of the prism face may be formed on FE.

To apply this device and method to color photometry it is necessary that a vertical stick be placed in the path of this colored beam casting a shadow on the screen, while a second standard light T_2 mounted on

a scale, casts a shadow close by. This second shadow is colored, being illuminated by the colored beam from S_2, while the first shadow receives the light from the standard; still, by moving the comparison lamp along the scale a point can be found at which the luminosities

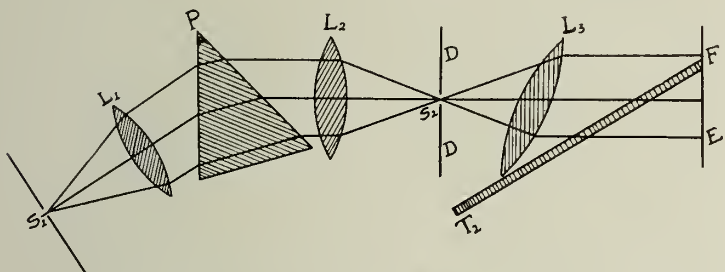


Fig. 124.—Abney's Apparatus for Obtaining Luminosity Curves of the Eye.

over the two appear equal. The determination of this point is, however, attended with difficulty much of which is overcome by the oscillation method described in 1886 by Abney and Festing. Abney found "That the best way of determining the intermediate point

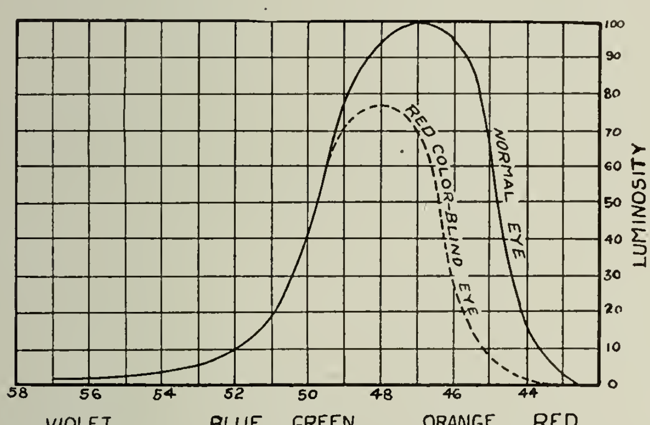


Fig. 125.—Luminosity Curves of a Normal and a Red Color Blind Eye. (After Abney.)

where the shadows balance is by oscillating the slide gently between two points when first one shadow and then the other is palpably too dark; the oscillations become shorter and shorter until the point of balance is determined." By pursuing this method throughout the whole spectrum Abney obtained the curves shown in Fig. 125. The full line curve is that representing the sensitivity curve of the normal

eye, the ordinates being the luminosities and the abscissæ the wave-lengths of light; we have also included in the dotted curve a representation of the sensitivity of a red color-blind observer.

213. Experience has demonstrated, however, that the sensitivity curve for different colors of radiation is a function of the intensity of radiation. That is to say, the maximum sensitivity point of the eye is not at a definite frequency or wave-length but varies with the intensity of illumination and shifts toward the red end of the spectrum for high intensity of illumination and toward the violet end of the spectrum for low intensities. For illumination of very high intensity the maximum physiological effects occur in the yellow region while,

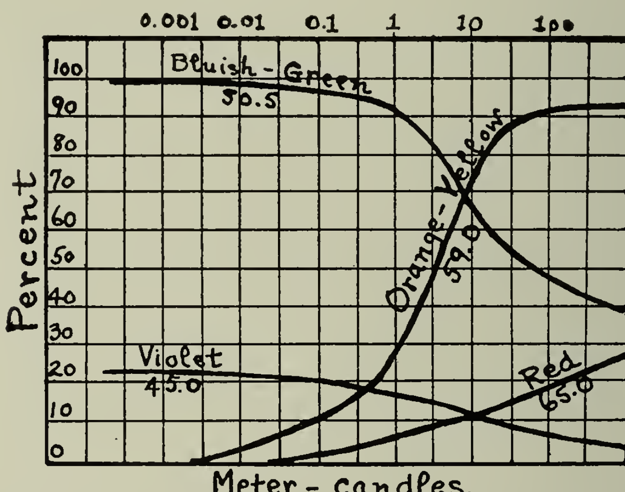


Fig. 126.—Curves of the Variation of the Relative Sensitivity of the Average Human Eye with the Intensity of Illumination for Red, Orange-Yellow, Bluish-Green and Violet Lights.

on the other hand, for very low intensity of illumination it appears in the greenish-blue region. Hence at high intensities yellow light requires less power for the same physiological effect than any other wave-length of radiant energy, while for low intensity bluish-green light requires a minimum power for the same physiological effect. A simple illustration of this is afforded in the following: if an orange-yellow light, as the flame carbon arc, and a bluish-green light, such as the mercury arc, appear of the same intensity at a distance of one hundred feet, then upon approaching the lamps the orange-yellow will appear to increase more rapidly in intensity than the bluish-green. From very short distances the yellow arc will appear "glaring" bright

while the mercury lamp will appear much less intense and in fact will appear very dim or weak in comparison. Upon receding from the lamps, however, the reverse phenomenon is observed, for the orange-yellow light fades out more rapidly than the bluish-green and will have disappeared when the bluish-green is still noticeably visible.

214. The accompanying diagrams in Fig. 126 illustrate the change of sensitivity with intensity for the average human eye for red light of wave-length 6,500, orange-yellow light 5,900, bluish-green light 5,050 and violet light of wave-length 4,500 Angstroms. For red and violet the sensitivity is low while for orange-yellow and bluish-green the sensitivity is high. For bluish-green radiation, however, the sensitivity is high at low and moderate intensities but falls off for high intensities, while for orange-yellow light the sensitivity is high at high intensities and falls off at medium and low values. Red light

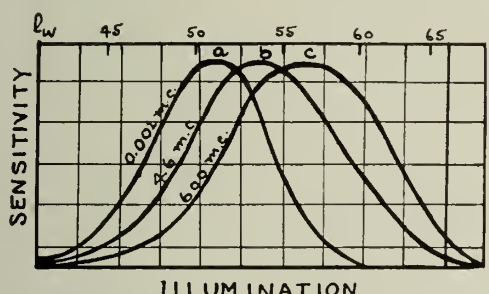


Fig. 127.—Approximate Sensitivity Curves of the Average Human Eye for Illumination Near the Threshold Value (medium illumination and high illumination).

vanishes from visibility still earlier than orange-yellow while violet is invisible even at very low intensities. The intensity of radiation varies inversely as the square of the distance but the physiologic effect of radiation does not vary exactly as the square of the distance but varies faster for the long wave-length end of the spectrum and somewhat slower for the shorter lengths of light.

215. The shape of the sensitivity curves also changes depending upon the intensity of illumination; for low intensity it is more peaked, showing that the sensitivity decreases more rapidly from a maximum towards the ends of the spectrum than it does for high illumination. These statements are substantiated by the curves of Fig. 127 showing the approximate sensitivities of an eye (a) for very low illumination near the threshold value of visibility or 0.001 meter-candle, (b) for medium illumination of 4.6 meter-candles and (c) for high illumination or 600 meter-candles. The maximum visibility region under the in-

tensities of illumination specified in the above three cases is 5,110 Angstroms for curve (a), 5,370 Angstroms for curve (b) and 5,650 Angstroms for curve (c).

216. It is of interest to compare the luminosity curves of the eye obtained when the yellow spot, the regions just outside the yellow spot and the fovea centralis are the subject of investigation. The comparative luminosities of the spectral colors as seen on the yellow spot are obtained by various color-patch and flicker methods either previously described or to be discussed later under color-vision. To get luminosity curves outside the yellow spot the following simple plan is adopted dependent upon the fact that in order that the images of the patches, for example, in the Abney methods, may fall outside the yellow spot

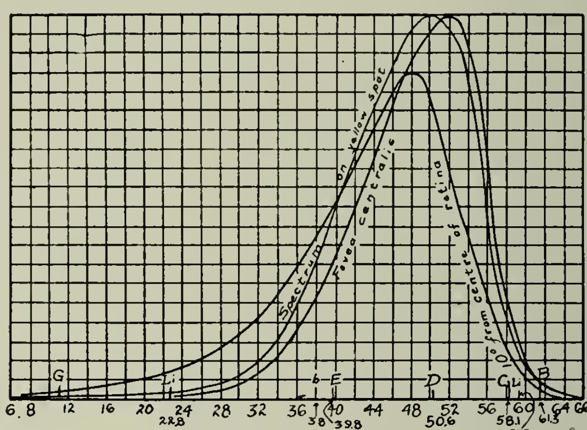


Fig. 128.—Sensitivity Curves of the Fovea Centralis, Yellow Spot and Area Ten Degrees from Center of Retina.

they should be received on the retina at least 5° from the center of the macula. If a spot is marked in a horizontal direction 5 inches away from the outside of the color rectangles used for comparison and the observer's eyes are 5 feet away from the patch and then the spot is looked at, the image of the rectangles will be received outside the extreme edge of the yellow spot. If this outside spot is illuminated by Balmain's paint and the axis of the eye under test, the other being occluded, is directed toward this point, the rectangles of white and color used for comparison will be clearly defined and the luminosities can be compared; they can, as a matter of fact, be compared with even greater facility than when observed with the center of the eye. The sensibility of the fovea centralis can be investigated by using extremely small rectangles; Abney employed a cube of one-quarter inch edge

in which the color and the white light each occupied one-half of one of the surfaces and the eye was kept at 5 feet. Observations showed that the fovea is about one-sixth more sensitive to the sodium (D) light than is the macula. The fovea appears less sensitive to the green and the blue than the macula. The results of Abney's experimentation on the fovea, the fovea centralis and ten degrees from the center of the retina are shown in Fig. 128.

XVI. THE COLOR-SENSE

217. We have discussed the light-sense in a considerable number of the preceding pages and have considered some phases of the relations between the light and color sensations in which, however, our interests were centered chiefly in the former rather than in the latter. We are now interested in the consideration of colors according to their hue, their saturation, their combination to produce white, the effects of environment upon them and similar topics. The *hue* or *tone* depends on the wave-length alone; the *saturation* or *purity* depends upon the white which is found added to nearly all existing colors except those of the spectrum. The hue changes constantly in the spectrum; the change reaches its greatest rapidity in the green-blue part of the spectrum, where a variation of ten wave-lengths produces a change of hue, but the rapidity diminishes toward the spectral extremities and in the extreme portions of the red and violet the hue remains the same. Therefore, notwithstanding the fact that the visible spectrum is generally considered as exhibiting only six or seven colors, there are theoretically present an infinite number. According to Koenig we can distinguish about 160 different hues in the spectrum, while according to the same author the eye can distinguish about 600 different degrees of brightness between the threshold and dazzling intensities. However, the number of hues which a person is able to distinguish is strikingly less than these figures would lead us to believe; in fact the number depends somewhat upon the manner in which the experiments are conducted. In Edridge-Green's apparatus, for instance, which is one of the latest we have, the principle involved therein is that of two opaque screens held over a spectrum and slightly separated from each other. One of these screens is then moved until the hue at its edge appears different from that at the edge of the other. Edridge-Green states that he has never met a man who could see more than twenty-nine monochromatic patches in the spectrum. Lord Rayleigh, who could distinguish the difference in hue between the two D lines (λ 5,890 and λ 5,896 Angstroms respectively), could distinguish only seventeen hues on Edridge-Green's apparatus and attributes the small number to the method of testing since he was able

by the use of a color box apparatus similar to that of Maxwell to distinguish many more hues. By the use of spectral apparatus fifty-five distinct spectral hues have been seen. By beginning with papers dyed to represent six spectral colors and by adding various intermediate hues Ridgeway obtained some thirty-six distinct hues. Steindler obtained data on the hue sensibility of twelve subjects and found as a mean of these eyes several maxima and minima in the curve showing the relation between relative hue sensibility and the wavelength. He found maxima at 4,550, 5,340 and 6,210 Angstroms and minima at 4,440, 4,920, 5,810 and 6,350 Angstroms. Calculations from this work as made by Nutting show that there are twenty-two of these colors "just easily perceptible" within the limits given.

218. The data and information which we have on the sensibility of the eye to *changes in saturation* are not very extensive or satisfactory. H. Aubert found that two to three degrees was the smallest sector of color that could be made just noticeable on rotating a white disc; with black and gray discs somewhat smaller sectors were recognized, showing in every case less than one per cent. Experiments on the differential limenal values of color sensitivity showed that on a black background the stimulus-increments for orange, blue and red were 0.95, 1.54 and 1.67 per cent., respectively, in order to produce a noticeable increase in saturation. A few years ago Geissler extended our knowledge along these lines; his experiments involved seven different degrees of saturation ranging from 360° of red to 110° of red plus 250° of gray of the same brightness. His results indicate that the stimulus-increments corresponding to just noticeable saturation differences are constant at about 4 degrees of gray within wide differences of stages of saturation; as an average of several observers it was found that 1.2 degrees of red when mixed with 358.8 degrees of gray caused a just perceptible appearance of color. Other experiments were carried out with red, yellow, green and blue colored papers and their corresponding grays both for each eye separately and for binocular vision. In general the averages for binocular vision were lower than for monocular vision. The results *in toto* when averaged for each of these colors gave as the mean limenal values of color saturation 2.23 degrees for red, 5.81 degrees for yellow, 7.19 degrees for green and 2.99 degrees for blue. This says that these values represent the smallest increments required to distinguish between color and no color. Experiments with a practically color-blind subject showed that his limenal values were high, being 37, 18, 140 and 8.25 degrees respectively for red, yellow, green and blue papers. This problem of saturation sensibility has been attacked from two extremes; one con-

sists in reducing a maximum saturated pigment color and the other of introducing more and more color into a colorless stimulus. Geissler employed the rotating double color disc with the Zimmerman colored and gray papers illuminated with an artificial daylight devised by Ives and Luckiesh. "In the first method he used red beginning maximum saturation, i. e., 360° of red, for both the inner and outer concentric components of the double disc and gradually added small amounts of gray, of the same brightness as the red as measured with a flicker photometer, to the inner or smaller disc until it appeared just perceptibly less saturated than the outer or larger disc. This procedure was then reversed, the outer disc being decreased in saturation until the change was just perceptible as compared with the inner disc whose saturation was kept constant." (Luckiesh; *Color and Its Applications.*)

219. *Color mixture.* The *equations of color* constitute the fundamental method for the examination of the color-sense. Two or three colors are mixed in different proportions until the observer says that this mixture is similar to a fourth given color, generally white. There are two distinct methods of mixing colors, one is by *addition* and the other by the *subtraction* of light rays. A body appears of a certain color because, as a rule, the chemical substance used in staining it has the property of absorbing certain visible rays and reflecting or transmitting others. The integral color of the light absorbed is said to be complementary to the color of the light remaining if the light was initially white. Any two complementary colors can be made to overlap and produce white by means of a simple apparatus in which a spectrum of sunlight is produced and two selected spectral regions can be deviated by means of prisms of small angles, or by means of adjustable mirrors, and combined into one spot by the aid of lenses; if they are complementary they will produce white. The *subtractive* primary colors have been termed red, yellow and blue; in reality they should be more exactly expressed as purple, yellow and blue-green. If the three subtractive primaries are superposed, black will result. If yellow and purple are superposed, red will result. The explanation of this last statement, which also serves as a basis for a superposition of any two or all three of the primaries, is that the blue of the purple is subtracted by the yellow, since yellow does not transmit blue rays, and as purple consists of red and blue rays only, the red rays remain to be reflected to the eye. In the case of the superposition of the three primaries we see that, where the yellow and purple overlap, red results; the blue-green disc, however, does not transmit red rays, hence total extinction of color results. The additive method has as

its primaries red, green and blue (or violet as some people prefer to call it). This method always tends toward the production of white, whereas the subtractive method tends toward the production of black. When red is added to green, yellow is produced and when blue is added to this combination white results. A table of complementary hues and wave-length complements is given below.

Color	*Color Complement*
Red	Blue-green (cyan blue)
Orange-red	Green-blue (bluish cyan)
Orange	Blue
Yellow	Blue-violet
Yellow-green	Violet-purple
Green	Purple (magenta).

Wave-length of Complementary Spectral Hues in Angstroms

6,562	4,921
6,077	4,897
5,853	4,854
5,739	4,821
5,671	4,645
5,644	4,618
5,636	4,330.

220. Very simple apparatus will permit of fairly accurate study and demonstration of these elementary color effects. Maxwell's discs offer a ready means of mixing colors. Colored papers cut in circles and slit along one of the radii can be overlapped to any degree and by the use of circles of various sizes a number of mixtures can be produced upon the same disc, when it is set into motion at a sufficiently high speed, by virtue of the phenomenon of persistence of vision. Lambert's device is a simple contrivance for color mixing; it consists of a glass plate set practically in a vertical position at some little distance from two colored objects lying on a table and at opposite sides of the plate; the glass plate transmits rays from one object while it reflects from one of its faces light from the second body: the eye receiving both stimuli experiences the resultant color sensation. And again, by looking at two colors, placed side by side, through a double refracting prism, they will be seen separated by a strip the coloration of which will be that of the mixture. Painters frequently use mixtures of coloring matter but the colors which are obtained are often not in

accord with those which are obtained by other methods. A mixture of yellow and blue pigments gives green, while with a revolving disc there is obtained a grayish-white. This is explicable on the basis that in a mixture of yellow and blue pigments the superficial molecules send back yellow and blue light; together these produce the impression of white as on the revolving disc. The blue molecules situated deeper in the layer also send back blue light just the same as the superficial layers but it is not pure for the spectroscope shows that it contains green, blue and violet. The deeper seated molecules of yellow in turn return red, yellow and green rays. Generally the molecules send back only rays of the colors which they allow to pass. Hence only green rays, reflected by the deeper yellow molecules, can pass through the superficial blue molecules and likewise the green rays reflected by the deeper blue molecules can pass through the superficial yellow ones; the result is, therefore, a green colored paint or pigment, this green being mixed with the white light reflected by the surface.

221. *Newton's color table.* The "king of physicists" devised a table to give a graphical representation of the results obtained by mixing colors. This table is shown in Fig. 129. Suppose, for example, that we desire to know the result of mixing three parts of green with two parts of blue and one of red. The red and green are first joined in the diagram by a straight line which is divided into segments at the point p such that the distance of this point from the green may be one-third of its distance from the red. The point p is then the place or position of the mixture of the red and green. This point p is then joined to the blue by a second straight line which is so divided at a point q that the distance pq is to the distance qb (where b represents the blue point on the color diagram) in the ratio of 2 to 4; q is, therefore, the point of mixture of the three colors. Drawing, then, the line oq and continuing it until it intersects the spectral curve we find that the color of the mixture is bluish-green diluted, of course, with white since some of the red, green and blue will combine to form white.

The form of this color curve of Newton's is, up to a certain point, arbitrary: there is the necessity of considering the quantity of the colors. In Newton's scheme, therefore, one must consider as equal the quantities of two complementary colors which, when mixed, give white: furthermore, if we take any other two complementary colors, one must also consider as equal the quantities of these colors when, upon mixture, they give a white of the same brightness as the former mixture of complementaries. Maxwell and Helmholtz used other definitions. The table of Newton also shows that, excepting purple,

one cannot produce new colors by mixing spectral colors for it is always possible, after having found the position of the point representing the mixture, to draw a straight line passing through this point and the center and, by prolonging this line to meet the spectral curve, to thus find the color of the mixture diluted with white. Newton's table also shows that one can reproduce all existing hues by mixing, two by two, three colors properly chosen. Referring again to Fig. 129, let red, green and blue be selected and let them be connected by straight lines. If any spectral color is selected, it can be joined to the center of the circle by a straight line which must of necessity cut one of the sides of the blue-green-red triangle. At the point of intersection is found the mixture which is similar in hue to the spectral

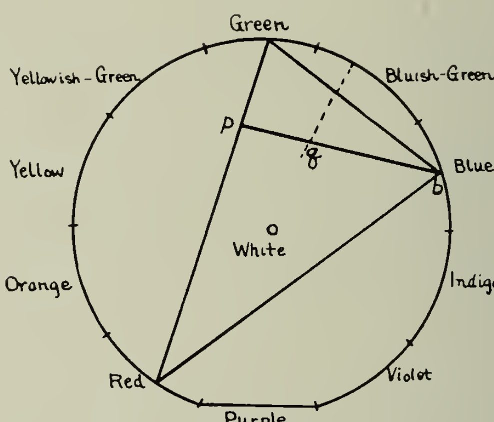


Fig. 129.—Table of Colors. (After Newton.)

color. Because of this peculiarity the normal eye is called trichromatic. It is to be observed that the two colors are said to be alike as to *hue* but they are not generally alike as to *purity*, the color of the mixture being diluted with white. There is a further requirement in this table and that is that the spectral colors must always have a greater purity, for if it were possible to reproduce a third color exactly by mixing two spectral hues these three colors would have to be placed in a straight line and the spectral curve would not be circular. This condition is not, however, fulfilled as we shall see from the work of Maxwell.

222. *Maxwell's color table.* Newton's work was verified by Maxwell; but the latter found that the spectral colors cannot be arranged on a circle because there are portions of the spectrum the colors of which can be exactly reproduced by the mixture of two given colors and which, therefore, must be placed on a straight line. Fig. 130

shows Maxwell's spectral curve. This curve was determined experimentally by Maxwell while Newton's was largely a mental conception. The apparatus of Maxwell consisted of a box, a sectional diagram of

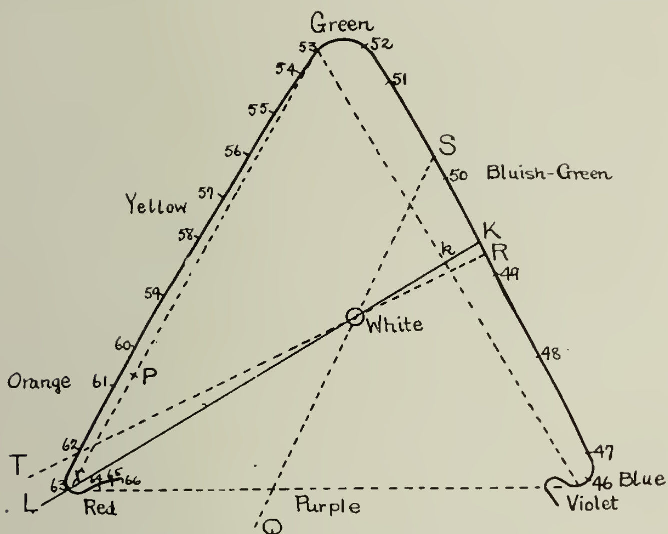


Fig. 130.—Color Table of Maxwell.

which is shown in Fig. 131. At E there is a narrow slit through which passes light. This light is, in turn, reflected by the mirror e to the prisms P_1 and P_2 through which it passes to the concave mirror S.

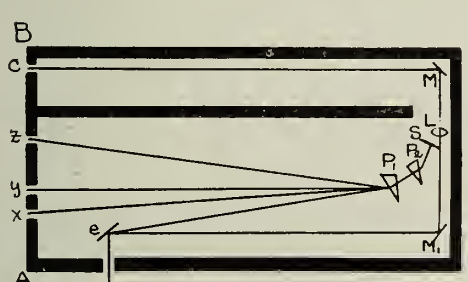


Fig. 131.—Color Box of Maxwell.

The mirror S reflects the light back through the prisms and there is formed a spectrum along the side of the box AB. At this end of the apparatus there are also three movable slits x, y and z which permit of the selection of any portions of the spectral colors which may be desired. This device is optically reversible provided that these slits

are illuminated by the same spectral regions as would have, in turn, been found at these positions when the light was sent in at E. Hence it is possible to illuminate the three slits x, y and z by white light; an eye at E then sees the prism P colored by a mixture of the three colors which a similar source placed at E would have projected onto the slits. Through the slit C white light can be allowed to enter and after reflection by the mirror M, concentration by the lens L and a second reflection from a ground-glass plate M_1 blackened at the rear surface, an eye at E will see this plate at the side of the prism and can thus compare brightness and color of the mixture with that of the white light admitted through C. By proper adjustment of the sizes and positions of the slits there can be obtained a spectral mixture which is not distinguishable from the white light reflected by M_1 either as to brightness or color.

223. In the determination of his color table Maxwell selected the three following colors as standards:—

	Red (R.)	Green (G.)	Blue (Bl.)
Wave-length (Angstroms)....	6,300	5,280	4,570

He then gave these radiations access to the three slits respectively of his color box and by regulating the widths of the slits he produced a mixture which did not differ either in hue or brightness from the white introduced through the second lens-mirror system (CMM_1E of Fig. 131) just described. He measured the widths of the slits as $x = 2.36$ mms., $y = 3.99$ mms. and $z = 3.87$ mms. and by designating the white, which remained constant throughout his experiments, by W he wrote as his color equation

$$2.36 \text{ R.} + 3.99 \text{ G.} + 3.87 \text{ Bl.} = \text{W.}$$

By displacing the slit x so as to give access to orange light and by regulating the widths of the slits he obtained as another color equation

$$2.04 \text{ Or.} + 3.25 \text{ G.} + 3.88 \text{ Bl.} = \text{W.}$$

Since the white is equal in both equations, we have, therefore, an equality of equations and a little arithmetic shows that

$$1 \text{ Or.} = 1.155 \text{ R.} + 0.362 \text{ G.} - 0.006 \text{ Bl.}$$

A repetition of the measurements for other colors, always combining two of the standard colors with the color in question to give white, was made by Maxwell and demonstrated that all colors of the spectrum can be expressed in terms of three primaries. The accompanying table gives the results of these measurements.

Color	Quantity	Wave-length		Red	Green	Blue	Sum	Unity
Red	5.63	(6630)	=	2.36	+ 0.05	+ 0.36	2.77	2.032
	2.36	(6300)	=	2.36	+ 0.00	+ 0.00	2.36	1.000
Orange	2.04	(6060)	=	2.36	+ 0.74	— 0.01	3.09	0.662
Yellow	2.79	(5830)	=	2.36	+ 2.45	— 0.01	4.80	0.582
	3.20	(5620)	=	1.55	+ 3.99	— 0.01	5.43	0.589
	3.30	(5440)	=	0.42	+ 3.99	— 0.03	4.38	0.754
Green	3.99	(5280)	=	0.00	+ 3.99	+ 0.00	3.99	1.000
	5.26	(5130)	=	— 0.33	+ 3.99	+ 0.44	4.10	1.282
	7.87	(5000)	=	— 0.43	+ 3.99	+ 2.22	5.77	1.362
Blue	7.83	(4880)	=	— 0.39	+ 2.67	+ 3.87	6.15	1.275
	5.14	(4770)	=	— 0.24	+ 0.98	+ 3.87	4.61	1.116
	4.28	(4670)	=	— 0.14	+ 0.14	+ 3.87	3.87	1.105
Indigo	3.87	(4570)	=	0.00	+ 0.00	+ 3.87	3.87	1.000
	4.10	(4490)	=	0.08	+ 0.03	+ 3.87	3.98	1.032
	5.59	(4410)	=	0.14	+ 0.09	+ 3.87	4.10	1.362
Violet	8.09	(4340)	=	0.04	— 0.23	+ 3.87	3.68	2.197

224. By dividing each equation by the coefficient of the color on the left in each of the above expressions we can obtain the value cor-

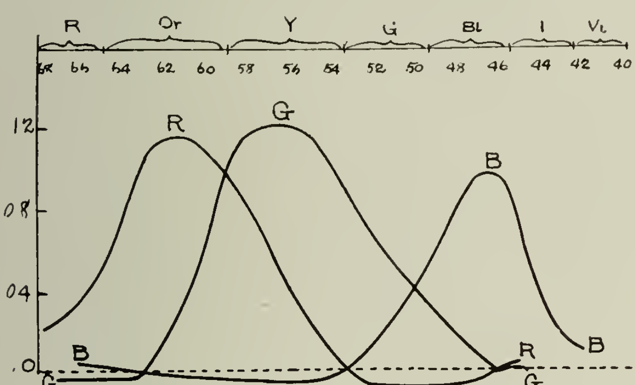


Fig. 132.—Color Curves of Maxwell.

responding to a slit width of one millimeter. The results can be expressed in the form of three curves designated as *R*, *G* and *B* in Fig. 132 corresponding to the three standard colors. The numerals underneath are the wave-lengths of the different colors of the spectrum and the positions of the three points in which the curves cut the vertical axis indicate the quantities of the three standard colors needed to produce the mixture. The significance of the negative signs attached to various colors, in general to the blue or red, is readily grasped. By writing the equation of the orange as

$$2.79 \text{ Y.} + 0.01 \text{ Bl.} = 2.36 \text{ R.} + 2.45 \text{ G.}$$

we see that we cannot, with the three standard colors, produce a

mixture exactly like yellow, but must add a little blue to the yellow so that it may be like the mixture of red and green.

If one desires to use the foregoing color table to solve equations of color mixtures one must multiply the quantities found in the table under the heading "quantity" by the figures indicated in the column called "unity" in order to obtain a result expressed by the width of the slit in millimeters. These units are obtained by dividing the numbers expressing the quantity or coefficient of any color by the sum of the component colors. The standard colors have, necessarily, a unit ratio between the coefficient of the specified color and the sum of the component colors; but for all other colors we are obliged to select the units in a different manner. The sum of the three components for *green* is, from the table,

$$2.36 + 2.45 - 0.01 = 4.80,$$

while the width of the slit is 2.79 mms.: accordingly, then, the quantity of yellow passing through the slit of 2.36 mms. is 3.09, hence the unit of yellow corresponds in this case to a slit width of 0.582 mm.

225. To construct the spectral curve we draw initially an equilateral triangle as shown in Fig. 130 and place the three standard colors at the corners thereof. To find the position of the orange we commence by dividing, by virtue of the color equation for orange, the red-green side into two parts in the ratio of 0.74 green to 2.36 red. Let P be the point of division; this point is to be joined to the vertex of the angle of the blue by a straight line of which the length, l, is measured. The color at P is due either to a mixture of 2.36 R. + 0.74 G. or to a mixture of 3.09 Or. + 0.01 Bl. Hence the color in question must be placed on the prolongation of "l" slightly beyond the point P by an amount $\frac{0.01}{3.09}$ l. In the case in hand this amount is so small that the curve almost coincides with the dotted side of the triangle. However, a survey of the color equations for blue will show why the color curves lie outside the standard color triangle. A color which is situated in the interior of the triangle may be reproduced exactly by a mixture of the three standard colors. For a color on the outside, however, this is impossible and it is necessary to mix it with one of the standard colors in order that it may appear equal to the mixture of the other two. As nearly all of the spectral colors have one of the coefficients negative, practically the entire curve lies outside of the standard color triangle. This means that the mixture produced has a little less

purity than the spectral color. By means of the table of Maxwell we can construct the result of the mixture of any colors; if the colors on the same side of the triangular curve are mixed the resultant will have as much purity as the spectral colors but if two colors situated each on a different side are mixed the mixture will be strongly diluted with white.

226. Lastly, the table indicates a large number of pairs of complementary colors; that is, of colors which, mixed two by two in the proper proportions, give white. To find the color complementary to a given color we have only to prolong the line which joins it to the white until it meets the curve again. The point of intersection will be the complementary color and the quantities to be taken of each color are inversely proportional to their distances from white. An inspection of the table shows that the green colors from 5,700 to 4,950 Angstroms have no complementary colors in the spectrum; their complementaries are purples.

227. *Color-blindness.* It is said that about four per cent. of men are afflicted or affected with the form of dyschromatopsia known as Daltonism. There occurs in the spectrum for such persons a region which resembles white (gray) and which is commonly designated as the neutral point. For the Daltonists this neutral point occurs in the green-blue; they, therefore, see only two colors, one of which is usually called yellow and which fills the entire spectrum from the neutral point to the red extremity, and the other, which is designated as blue, extending from the neutral point to the violet end. The hue does not change in either of these two regions respectively; there are differences of purity and brightness only. The color called yellow includes the normal red, orange, yellow and green up to about 5,300 to 5,400 Angstroms. There are in this region differences of brightness only. The red and orange of the spectrum are often so feeble to such color-blind persons that they are not perceived as being present unless the spectrum is very clear. Proceeding, then, from 5,400 Angstroms the color becomes more and more grayish until, as it reaches the neutral point at 5,000 Angstroms, the color is apparently whitish-gray. The brightness also diminishes; the parts situated near the neutral point are usually darker than those situated at some distance from it. This may be due to the fact that this neutral point occurs in the green-blue region where the rays are most affected by the influence of absorption due to the yellow pigment of the macula. After the neutral region has been passed, another color designated as blue makes itself apparent and gains in purity until the 4,600 Angstrom point is reached when the brightness and purity become a maximum. From

this point on there are differences of brightness only. Dichromates see, therefore, only two colors, but it is difficult to tell which they are. Dalton's investigations convinced him that he had only two and at the most three color sensations which he called yellow, blue and perhaps purple; his blue and purple coincided with those of normal color-visioned people. He says that "The part of the image which others call red appears to me little more than a shade or defect of light; after that the orange, yellow and green seem one color which descends pretty uniformly from an intense and a rare yellow, making what I should call different shades of yellow. The difference between the green part and the blue part is very striking to my eye; they seem to be strongly contrasted. That between the blue and the purple much less so. The purple appears to be blue, much darkened and condensed." If, then, we designate the colors as blue and yellow, it is not a surety that these spectral colors give them the same impressions as those which we obtain by yellow and blue.

Ophthalmic literature contains the interesting case of a person whose color-vision was normal in one eye while the other eye exhibited an anomaly analogous to ordinary Daltonism. The case was investigated by Hippel, who found that the neutral point, which was situated at 5,120 Angstroms, divided the spectrum into a yellow and a blue portion. The red and green appeared of the same hue as the yellow but were less bright. From a comparison of the sodium yellow line as seen by each of these eyes it was reported that the appearance was the same for both eyes except that there was a slight diminution of brightness for the dichromic eye. The same was found true in the case of the blues, hence it may be concluded that the sensations which are designated by Daltonists as yellow and blue are identical with those of normal persons.

228. Color-blind persons recognize the equation of the normal eye, hence the colors which are complementary in one case are also complementary in the other condition. Of course the complement to the neutral region must appear to them as either gray or be totally invisible, as well as the colors situated on the diameter of the table which joins them. But, on the other hand, color-blind persons recognize as similar mixtures which are by no means such for normal eyes. The impression of any color of the spectrum can be reproduced for a Daltonist by mixtures of two colors; this is true also of white. Maxwell, by using green and blue, obtained as the color equation for white in a case of dichromasia the following:

$$4.28 \text{ G.} + 4.20 \text{ Bl.} = \text{W.}$$

The position of this mixture color is represented on the Maxwell table given in Fig. 130 by the letter k; the letter K indicates the corresponding spectral color which is the neutral point. Since the Daltonist recognizes the equation of normal eyes, which is according to Maxwell,

$$2.36\text{ R.} + 3.99\text{ G.} + 3.87\text{ Bl.} = \text{W.}$$

we can equate these two expressions and obtain

$$2.36\text{ R.} - 0.29\text{ G.} - 0.33\text{ Bl.} = \text{O.}$$

This last equation would not, therefore, represent any impression on the dichromatic eye but would represent in a certain way the element which is lacking. This place is marked by the letter L in Fig. 130. Since L is slightly outside of the spectral curve it represents a color which does not exist and is, therefore, fictitious but which must be

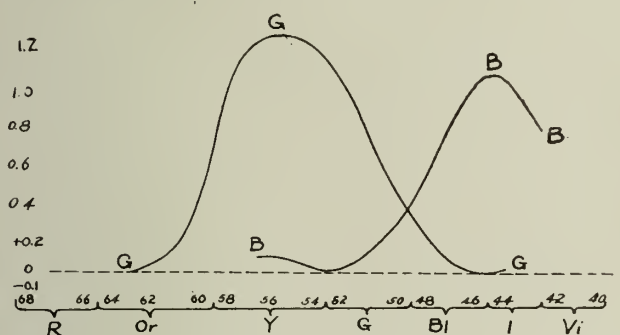


Fig. 133.—Color Curves of a Dichromatic. (After Maxwell.)

supposed to be much purer than the corresponding spectral color on the equilateral triangle which is marked as l. Compared with L, l is to be considered as a mixture of white; it is not wholly invisible but is very feeble.

229. The results shown in Fig. 133 are the color curves of a dichromatic, after Maxwell. On the table of colors the whole chromatic system would be reduced to a straight line since all the colors which we can produce by mixing two given colors must be placed on the straight line which joins them. An examination of a number of dichromatics shows that the neutral position is not exactly the same in all; it varies between 4,920 and 5,020 Angstroms. In Fig. 130 these two limits are marked as R and S, consequently the direction of the neutral diameter would vary between RT and SQ. Therefore, there results a difference between dichromatics whose neutral point is situated nearer R or nearer S. In the first case the neutral diameter

passes through the bluish-green at one extremity and the reddish-orange or orange at the other end; the spectrum appears shortened in the red end. In the second class the neutral point corresponds to a color situated near the green the complementary of which is purple and not found in the spectrum. As the colors complementary to the gray parts of the spectrum do not correspond to the red end, the red will therefore preserve its ordinary intensity and the spectrum will not be shortened. These two forms are often differentiated, the former being designated as *anerythropsia* or red-blindness and the latter as *achloropsia* or green-blindness. This distinction has been followed by a large number of scientists; there seems to be a reasonable objection to this differentiation on the basis that the neutral diameters, which have been represented by SQ and RT in Fig. 130, do not represent the only two possibilities since other intermediary forms appear to exist.

230. We have discussed dichromasia because it is the most pronounced or the most frequently found of all color disturbances or abnormalities. But there exist also abnormal *trichromasia* and *monochromasia*. Monochromatic eyes manifest all signs of weakness such as photophobia and diminution of visual acuity: color-blindness, on the other hand, implies no other abnormality. In *monochromasia* differences of color do not exist and the only variations such subjects experience are those of brightness differences. The spectrum appears to them simply as a luminous band of which the maximum brightness appears in the green (5,200 Angstroms) rather than in the yellow as in the normal eye. This abnormality is rare but extremely well established when it does occur. There is, furthermore, a class of eyes, discovered in 1880 by Lord Rayleigh, for which the generally accepted assertion cannot be made that an equation of color which is true for a normal eye remains true for all eyes, as well for dichromatic as for normal color-visioned eyes. Rayleigh produced a mixture of spectral red and spectral yellow which appeared to him identical with spectral yellow and had various observers compare the two fields. For the majority of persons tested the two hues were identical but others declared they saw no resemblance, for the pure color appeared yellow to them while the compound color appeared red. To make this ''mixture'' color appear like the pure spectral yellow there had to be added a considerable amount of green; in fact so much of this latter color was demanded that the resulting color appeared greenish to the normal eye. The mixture for Rayleigh was 3.13 R. + 1.00 G. while for a person possessing the above form of *abnormal trichromasia* the color equation for yellow was 1.5 R. + 1.0 G. No other abnormali-

ties were discovered in such persons; they were not in any sense of the word dichromatics. This anomaly appears to be as frequent as Daltonism; Koenig and Dieterici discovered three cases of it out of seventy persons examined.

There are other slight differences which occur in the color tables of normal eyes and are doubtless due to the fact that portions of the rays are absorbed by the media of the eye; this absorption is more pronounced in some persons than in others. Thus the crystalline, as it becomes in general slightly yellowish in advancing years, absorbs some of the blue rays. Hence a mixture of blue and yellow which would appear white to the normal eye, must appear slightly yellowish to the older eye. After cataract extraction the patient quite often, at the first moment, sees everything blue.

231. *Topography of color fields.* We have evidence in our own eyes that the color-sense has been evolved. A very simple experiment carried out by the reader will convince him of the facts that the sensation of light exists quite regardless of color and that, in turn, the two do exist together. Let the experimenter put a green button on a sheet of black paper in a well lighted room. Standing some feet away let him close one eye and let the green button be observed in the ordinary manner. The image will fall on the center of the retina, the fovea centralis. Then let the head and eye be turned together so that the image of the green button will fall on a portion of the periphery of the retina. At a certain distance from the axis the green spot will appear white, hence the object will be seen but no notion of its hue would be forthcoming unless the image had been initially received on the center of the retina. It is, of course, to be noted that the brightness of the color and the size of the spot cause variations in the angle at which the color disappears. If the brightness be feeble and the angle which the colored disc subtends on the retina be very small, a shift of the axis of the eye by a very few degrees will suffice to render the spot colorless. This simple experiment is worthy of consideration as it shows that the retina is most sensitive to color in the region which the axis of the eye cuts and that there is a gradual diminution in sensitiveness to color though not necessarily to light as the periphery is approached. This is what would be expected if the eye has followed the laws of evolution. Every individual, therefore, is color-blind though not light blind in the outer retinal regions. The most difficult color (exclusive of white, which should be considered a combination color) to cause to disappear is the blue.

232. These color-blind conditions in the peripheral regions are of considerable interest to the physicist, physiologist and the psy-

chologist; to the ophthalmologist they are of particular interest only when contracted or abnormal color fields are found, for these are an aid in the diagnosis of disease. We shall confine our attention here to the normal eye when pure spectral colors are used, the eye being dark adapted. Sir William Abney describes in his book on *Researches on Color Vision* two forms of special apparatus for plotting the color fields. The first is a *perimeter* of ordinary form but modified for use in a dark room. The perimeter is an instrument consisting essentially of a semi-circular arc, graduated into 5°—10° portions, which can be rotated about an axis piercing the center of the metal arc. The diameter of the arc is usually about 18 to 24 inches. Abney modified this for use with spectrum colors "by fastening a mirror to a ball-and-socket joint placed just below the center of the sphere, that is, the position occupied by the eye. By means of an arm the mirror can reflect along the arc any beam of light falling upon it. The light reflected was so arranged that a circular spot of any desired color could be caused to travel along the arc (which was covered with white) when it occupied any angle with the vertical. The distance of the arc was so arranged that the image of the first surface of the first prism was in focus on it, and the spot was formed by placing a diaphragm against the prism. The intensity of the color could be altered (1) by closing or opening the slit through which the colored ray issued; (2) by placing a graduated annulus in front of the slit; (3) by closing the slit of the collimator and (4) by using sectors in front of either slit." The mode of operation was to cover one eye and keep the other eye directed at the center of the semi-circle marked by a pin point of Balmain's luminous paint. A spot of colored light was caused to travel along the white arc; when the color of the light was judged to have gone the reading of the arc was taken.

233. Making use of this form of apparatus or one of a similar nature the question of the similarity of fields for different colors can be investigated. It is essential to know whether the fields for each color are of the same form when the illumination is adjusted so that one point in a field of one color coincides with one point in the field of a different color. Two sets of experiments were made by Abney using intensities of 4.5 and 0.23 amyl-acetate lamps respectively. The results are shown in Figs. 134 and 135. The diagrams show that the fields for properly selected luminosities are evidently the same, the fields of the yellow sodium and the red lithium being very close to one another. A comparison of the fields for the yellow sodium and red lithium rays in the second of these diagrams with the green (wave-

length 5,085 Angstroms) in the first diagram shows that they are practically identical.

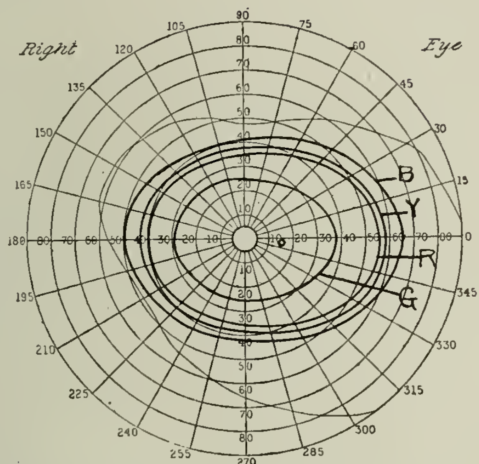


Fig. 134.—Investigations on Similarity of Fields for Different Colors. (Abney.) The intensity was 4.5 units.

An investigation as to the differences in the extent of field caused by differences in illumination was carried out by Abney in horizontal

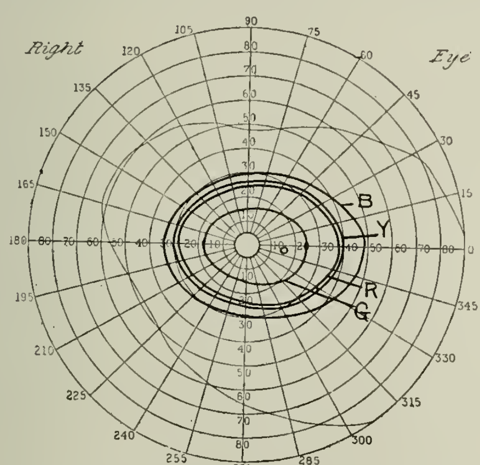


Fig. 135.—Investigations on Similarity of Fields for Different Colors. (Abney.) The intensity was 0.23 unit.

directions only. These experiments showed that the average diminution in field for each reduction of half intensity was 3.75° on the temporal side and on the nasal side about 3°. Curves plotted from

his data, using the intensities of the illumination as ordinates and the degrees to the nasal or temporal side of the direct fixation line as abscissæ, show that there is a linear relation existing between the limits of the fields for all colors and luminosities; there is apparently a diminution in the angle of field in an arithmetic progression as the intensity diminishes in geometrical progression.

234. Other sets of experiments were carried out to ascertain the extent of the color fields for all colors when a slit was passed unaltered through the spectrum. When the curves are plotted from the data thus obtained and the distance apart of the nasal from the temporal ordinates is given it will be found that when the latter reads 40°, for example, the former reads 30° no matter what the color may be, and that when the field increases about 7.5° on the temporal side the field on the nasal side increases nearly 6°.

It is known that the loss of light in the center of the retina depends quite largely upon the size of the spot of light viewed. This indicates that the boundaries of a field would contract if the spot of light viewed is diminished. Experimentation has demonstrated that, between apertures subtending 4° 28′ and 10′, the fields decrease in extent and that there is a linear relationship existing between the field in degrees and the diameter of the aperture. For each diminution in aperture to one-half diameter the diminution in field on the temporal side is 5° and on the nasal side 4°.

235. *Growth and decay of color sensations.* The problem of the growth and decay of color sensations as dependent upon the effect of time of exposure and intensity of the stimuli has been the subject of numerous investigations on the part of Bloch, Charpentier, Sulzer, Broca, Ferry, Porter and others. Colors are often produced due to stimuli which have no single color as commonly understood; that is to say, if a disc composed of black and white be rotated at the proper rate—which is moderately slow—colors appear upon the edges of the sectors instead of gray. Fechner in 1838 was probably the first to describe these subjective colors; many have studied this problem and agree as to the experimental results but not in their explanations. In 1894 Benham produced a disc somewhat different from those of preceding investigators; one form of disc which, when rotated, shows the colors in striking manner consists of two half circles of black and white, the white sector carrying arcs of black laid down in a step-like arrangement, each set of arcs having a shorter radius and all having their common center at the center of the disc. When this apparatus is rotated the colors are seen in a very striking manner. In general, when black is followed by white at a moderate speed a sensation of red

is produced, but if white is followed by black there results a blue sensation. By the introduction of various angular intervals, as is done in the Benham apparatus, the sensations of intermediate colors are experienced. By rotation of the disc in one direction a blue sensation is aroused in the inner ring and red in the outer; if the rotation of the disc is reversed the colors are also reversed in their order. The phenomena have not been explained satisfactorily: no doubt retinal inertia and the difference in the rates of growth and decay of the color sensations are important factors in these subjective colors. These colored effects are often observed when the eye is run rapidly over black and white surfaces in the field of vision. A simple device for showing these Fechner colors is one containing black and white sectors; on rotating such a disc at a certain speed it will have the appearance of a greenish hue but at a more rapid rate of motion it appears reddish. Rood employed an opaque disc with four open sectors each of seven degrees; through this rotating disc he viewed a clouded sky; with a rate of nine revolutions per second the sky appeared of a deep crimson hue except for a small space in the center of the visual field which remained constantly yellow, due probably to selective absorption in the "yellow spot" of the retina. When the rate of motion was eleven and a half revolutions per second the field appeared bluish-green. Finnigan and Moore made the lines on a disc a centimeter wide and found that on rotation the band following the black was bordered with a red over the black and on that which came from white to black the band was bordered on the white with a blue to green color leaving the band quite black. Bidwell's explanations as to these effects appear to be borne out by these experiments; his explanation, in essentials, is that the red color of the fine lines following the black are due to sympathetic spreading of the red sensations whilst the blue color of the fine lines following the white is due to the lack of such sympathetic action when the illumination is suddenly shut off, leaving the other sensations exhibited on the black surface on which these lines are practically viewed and which the retina takes as part of the lines.

When a flash of white light is received on the retina there are what are known as *positive recurrent optic images.* These appear to have been first accidentally discovered by Professor W. Young while experimenting with an electrical machine; he noticed that after a strong spark had illuminated any object it was seen at least twice, the second time about a quarter of a second after the first. Sometimes it was seen a third time or even a fourth. This is known as *recurrent vision.* When an object is illuminated by a discharge from a static electrical machine carrying a condenser and the eye is screened from the dis-

charge, Bidwell found that under favorable conditions six or seven recurrent images could be detected.

236. The recurrent image may be shown by means of a device due to Bidwell. This consists of a disc which can be turned about its center and which carries a small hole drilled near the periphery. The light from a projection lantern can be passed on to a screen through this aperture. When the disc is rotated so that the spot travels round the screen with a slight elongation in the line of travel, if the eyes are kept steadily fixed on the screen, there will be found a faint violet spot traveling behind the white oval separated by an interval of darkness. If the speed of rotation is increased the interval between the two spots will increase. Bidwell repeated his experiments with spectrum colors and found that one color gave no ghost, namely, red. The ghost to every other color is of a violet tinge. The time of rota-

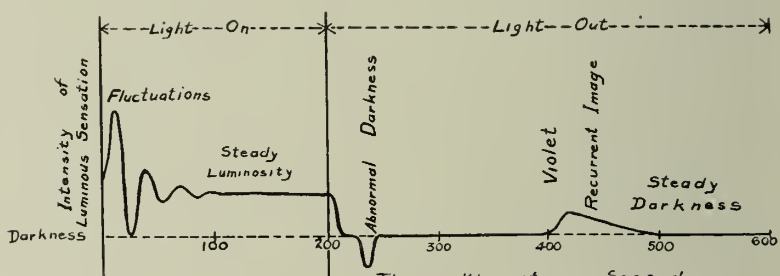


Fig. 136.—Growth and Decay of Luminous Sensations.

tion being known and the interval between the original spot and the ghost being measured, we have a means of calculating the interval that elapses between the first image and that caused by recurrent vision; Bidwell puts this at about one-fifth of a second.

237. Charpentier made many observations on the impressions received on the retina due to light. Charpentier's law can be stated in the following words:—"When darkness is succeeded by light, the stimulus which the retina first receives and which causes the sensation of luminosity is followed by a brief period of insensibility resulting in the sensation of momentary blackness. It appears that the dark period begins about one-sixtieth of a second after the light has first been admitted to the eye and lasts for about an equal time." Charpentier's apparatus for demonstrating and measuring the duration of this effect is simple: it consists of a blackened disc carrying a white sector. When the disc is illuminated by sunlight and turned rather slowly, the gaze being fixed upon the center, there appears upon the

white sector, close to the leading edge, a narrow but conspicuous dark band. The portion of the retina which at any moment is apparently occupied by the dark band is that upon which the light, reflected by the leading edge of the white sector, impinged one-sixtieth of a second before. A graphical representation of some of the results upon growth and decay of luminous sensations, abnormal darkness and recurrent images is given in Fig. 136.

238. The work of Broca and Sulzer is especially comprehensive in the field of investigation on the growth and decay of color sensations. The complete account of their apparatus and methods of experimentation is to be found in the *Journal de Physiologie et de Pathologie*

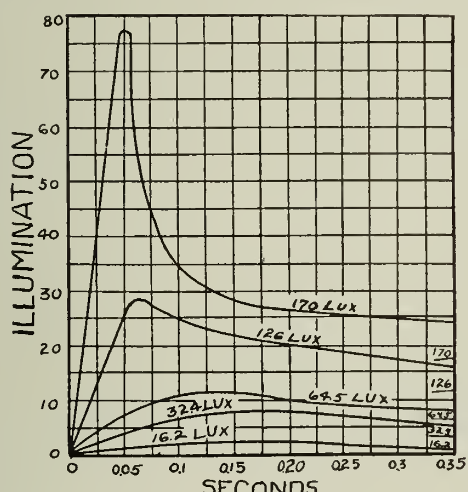
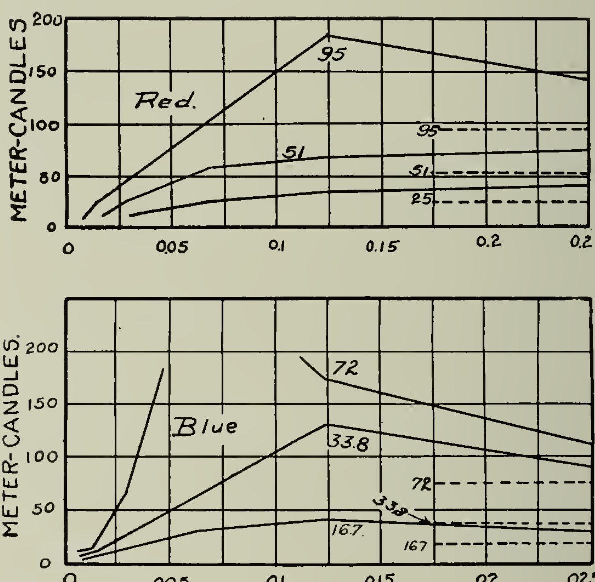


Fig. 137.—The Growth and Decay Curves for White Light Sensation. (After Broca and Sulzer.)

generale, 1902. They compared the brightness of a white screen illuminated by light of short duration produced by a disc, carrying a small opening and driven by an electric motor at speeds which could be definitely determined, with that due to a standard steady light. Some of their results for white, red and green lights are shown in Figs. 137, 138 and 139. These show that, except for lights of low intensity, the luminous sensation overshoots its final value. By this we mean that the maximum luminous sensation is passed a comparatively short time after the beginning of the exposure and that the luminous sensation reaches a steady value which is less than the maximum only after the lapse of an appreciable fraction of a second (of the order of 0.05 to 0.1 second) dependent more or less upon the intensity. The numbers on the curves indicate the final steady values

of the stimuli. The data obtained with colored lights indicate that under the stimulation from blue light the luminous sensations overshoot very much more than in the case of red or green lights. The luminous sensation, then, increases at first but soon commences to decay due to fatigue under the higher intensities; these effects are negligibly small at very low intensities. Working with red, green, blue and white lights Broca and Sulzer found that with blue the maximum sensation was at least five times the final and occurred about + 0.07 second after the initial exposure. Red and green overshoot to about double



Figs. 138, 139.—The Growth and Decay Curves of Color Sensations. (Red and Blue.)

the final intensities after about 0.13 second. Green overshoots scarcely at all, indicating either a very slight fatigue or else a very small lag in the fatigue behind the impression.

239. According to Talbot's law, a periodic illumination, such as would pass through a rotating sector, will produce on the eye the same luminous sensation as the mean constant illumination provided the period is below that producing flicker. This law has been quite rigidly proven experimentally for white light by Hyde but no satisfactory theoretical foundation is as yet forthcoming.

Exponential functions of time satisfactorily represent visual impression and fatigue, but we have not sufficient data to determine the

constants of these functions. The persistence of vision as determined by critical frequency has been employed by Allen with success in investigating color-blindness.

Luminosities of very short duration are perceptible if intense enough. A lightning flash of a millionth of a second is visible and by rotating mirrors flashes of light of one eight-millionth of a second have been perceived. Blondel and Rey studied the perception of lights of short duration at their range limits. Bloch had previously laid down the law that the excitation necessary to produce minimum sensation was constant and proportional to the product of the brightness and the duration; Charpentier verified this law for luminous durations between 0.00173 and 0.058 second. Blondel and Rey concluded that Bloch's law is applicable only to intense lights of very short duration; they deduced after a considerable amount of experimentation a single law of the form $(B - B_0)\ t = aB_0$ in which B_0 is the minimum perceptible brightness of the field, t the duration of the stimulus in seconds and a is a constant of time equal to 0.21 second.

240. *Effects of environment on the appearance of color.* It is known that the intensity, spectral character and distribution of the illuminating source, the adaptation of the retina for light and color, the duration of the stimulus and the character of the stimulus preceding the one under consideration, the size and position of the retinal image, the surface character of the colored medium and its surroundings all affect the appearance of a given color. The sensitivity of the various retinal zones explains why the size and position of the colored object affect its appearance. It has been found, using squares of one to sixteen square centimeters in area viewed from a distance of a meter, that the larger areas appear more saturated than the smaller ones. This saturating effect is greatest for violet and least for red, the remaining colors being affected as per their order in the color scale. Another phenomenon, presumably connected with the growth of color sensations and with chromatic aberration, is found when one views a red piece of paper on a blue-green background held at a meter or so from the eyes and under moderate illumination. If the paper be moved forward and backward while fixation is kept at a point in the plane in which the card is moved, the red area will appear to shake or oscillate and will not be apparently in the same plane as the blue-green paper.

It has been previously pointed out that the maximum spectral sensibility of a normal eye shifts toward the shorter wave-lengths at low intensities. Hence colors will shift in hue under low luminosities; for instance, a green pigment appears to be more bluish as the illumination

is greatly decreased. Colors appear more saturated at low than high intensities of illumination; intense illumination causes colors to appear very much less saturated. The spectral character of the light affects the appearance of the color of an object; a red fabric, for example, appears red because it has the ability to reflect chiefly the red rays, hence such a colored fabric would appear black under a light source possessing no red rays as in the case of a mercury arc. A colored fabric cannot, except in special cases, appear the same under two different illuminants; in other words, the eye is not capable of analyzing a color spectrally and it is, therefore, possible to produce colors which appear the same but whose spectral compositions differ. A purple, for instance, under noon sunlight appears a blue-purple while when illuminated by ordinary artificial light of continuous spectral character it appears a red-purple for the reason that artificial lights are proportionately richer in the longer wave-lengths while the maximum energy regions in natural light are in the green-blue region. The brightness or value of a pigment is also affected by the spectral character of the illuminant. Experiments on a series of Zimmerman papers by means of a reflectometer have been carried out under illumination from an overcast sky and from a tungsten lamp; the results of this work show that papers which have the ability to reflect the rays of light of longer wave-length predominantly appear relatively brighter under artificial light, while colors which reflect the shorter wave-lengths are relatively brighter or have a greater reflection coefficient under daylight illumination. Finally, the distribution of light is of some importance; when the light is so distributed that an appreciable amount of it is specularly reflected into the eye of an observer the color appears less saturated. A striking illustration of the effect of light distribution is found in the case of so-called changeable silks. When light strikes such material in certain directions it is more or less specularly reflected; in other directions the light penetrates the fabric which is then colored by multiple selective reflections. These two colors are roughly complementary.

241. *After-images.* Retinal excitation requires an appreciable time to decay after the stimulus has been removed. If the filament of an incandescent lamp is viewed for an instant and the eyelids are then closed a *positive* image of surprising distinctness will be seen which will persist for some time. If the eyes are kept closed, the less illuminated parts of the image disappear, while the more illuminated parts change color, becoming bluish, violet, orange and so forth in turn. The image finally disappears only to reappear with a repetition of the foregoing series of color changes. The image will then reach a

state of decay when it appears darker than the surroundings, coupled with these changes in color or hue. Helmholtz explained the colored after-images obtained in the above manner by assuming different rates of decay of the three hypothetical color sensations which are the basis of the Young-Helmholtz theory of color-vision. The *negative* after-image is the complement of the original color; if the object we look at is white the negative after-image is black. This after-image is explained as being due to retinal fatigue produced by the original bright image of the white or colored objects. On stimulating the whole retina with white light the portion previously fatigued does not respond in the same degree as the unfatigued portions. The question of after-images is intimately connected with the retinal conditions as influenced by stimulation; after-images are very quickly and pronouncedly obtained when objects are viewed after the eye has been rested in darkness, as when one, for instance, views an object on a wall for a second just after awakening and then fixes his gaze upon the clear wall at some distance from the original object. It is difficult to reconcile all the facts obtained from studies on after-images with the fatigue hypothesis of Helmholtz. Hering proposed an explanation of these phenomena on the basis that the retina is not fatigued but that a metabolic change is aroused which is opposite in character to that produced by the original stimulation. After-images are, of course, produced by fixing colored objects; they usually appear approximately complementary in hue to the original stimulus. If a colored triangle of red, green and blue is viewed, for instance, approximately complementary colors will be seen.

After-images play an important part in vision, especially in viewing paintings and many other colored objects. If a blue sky-line is viewed in a painting in juxtaposition to a green landscape, there will be sufficient shifting of the eye, even though it is fairly definitely fixed, to cause a shifting of the dividing line upon the retina. There will result, then, a pinkish after-image due to the green as well as to the blue which will, in shifting above and below the dividing or horizontal line give an effect of vividness or ''life'' to the picture. As a general rule the color appears to become less saturated and often a change of hue results after steady fixation upon a colored object. If a background of red, carrying a patch of black, is fixed for a few seconds and then, without changing the fixation, the black patch is removed it will be found that the red occupying this spot will be more luminous than its surroundings and of a more saturated reddish appearance.

The longer the time of fixation the longer does the negative after-image exist. Purkinje states that there is an exact proportion; each

additional second of fixation increasing the duration of the after-image some twenty seconds. Aubert found that when the sun was regarded for three seconds the after-image persisted about forty seconds, while if the time of gaze was five seconds the image lasted about five minutes. The brighter the object the longer will be the duration of the image.

242. *Successive contrast* further complicates the appearance of colors. If the retina is stimulated with red and the eye is suddenly fixed upon a green color this latter will appear more intense or saturated in color than if the previous stimulation under red had not taken place.

243. *Simultaneous contrast* greatly modifies our judgments of colors. On viewing a gray pattern on a black background it appears brighter than when viewed upon a light background. The effect is so marked that a much darker gray can be placed on the black background and still appear brighter than the one on the white ground. If a series of gray papers of different shades are placed edge to edge it will be found that the edge of a lighter gray strip which is adjacent to a darker one will appear brighter than the outer edge of the brighter gray strip. The intensity of the contrast effect diminishes rapidly as one passes away from the point of maximum contrast. When two colors, such as red and blue, are in juxtaposition they appear more saturated and deeper in hue. If the colors are separated the contrast effect nearly disappears. If, for example, a disc of green is placed on a larger disc of red the contrast is very effective, but if the smaller disc is surrounded with a black circle the effect is reduced. If a gray figure is placed upon a green background, the gray figure will appear of a pink hue; the contrast hue thus induced is approximately complementary to the exciting color. Hering devised a striking demonstration of binocular contrast: red and blue glasses were placed in front of the two eyes respectively; the glasses sloped away from the eyes from the nasal to the temporal sides. A white image introduced from the sides by reflection permitted a control of the saturation. A black stripe on a white background is doubled by increasing or decreasing the visual divergence. The stripe seen through the red glass appears green and through the blue glass appears yellow; the observed background appears spotted, alternately blue and red and at times a purplish white. Helmholtz, Brücke and others contend that the contrast effects are not of a physiological nature but are due to errors of judgment; that is to say, through the influence of an adjacent color our "standard white" is modified so that our mental judgment is also affected. The whole effect would then be of a psychological nature

according to these notions. There appears to be no agreement as to the true explanation at the present time. Contrast may be due to unconscious eye movements, to fluctuations and incipient retinal fatigue, to errors of judgment or to some cause not yet discovered. Mayer conducted experiments in which the contrast color could be matched by means of rotating color discs thus obtaining quantitative measurements; he found that the subjective contrast colors were perceptible when viewed through a small opening for exposures as short as one one-thousandth of a second; they were also perceptible with instantaneous illumination from an electric spark in which the duration of illumination was of the order of one ten-millionth of a second. From these experiments he concluded that fluctuations of judgment could not be entertained as a satisfactory hypothesis for the explanation of subjective color contrast because of the extremely short period of time of exposure. But, in support of the hypothesis of errors of judgment, Edridge-Green contends "That all our estimations of color are only relative and formed in association with *memory* and the definite objective light which falls upon the eye. In many of the most striking contrast experiments the color which causes the false interpretation is not perceived at all; for instance, if a sheet of pale-green paper be taken for white, a piece of gray paper upon it appears rose-colored, but appears colorless when it is recognized that the paper is pale-green and not white."

244. *Irradiation.* There yet remains for brief consideration the phenomenon of irradiation: this name is applied to the apparent increase in size of objects as they are increased in brightness. We know, for instance, that the filament of an incandescent lamp appears to increase as the temperature of the wire is raised from a dull red to its normal temperature and, yet again, the crescent of the new moon appears larger than the remainder of the disc. This effect has been attributed by many to what is known as a spreading of the retinal image on account of a stimulation of nerves outside of the actual geometrical boundaries of the image, while others attribute the effect to the aberrations in the optical system of the eye. The phenomenon of irradiation may be easily illustrated by constructing two background cards of the same size, one of white and the other of black, and placing upon each of these a much smaller card so arranged that the small black square shall rest upon the outer white card in the one case and the small white square shall lie upon the black background in the second case. The inner white square appears larger than the inner black square under high illumination, yet both are identical in size. The phenomenon of simultaneous brightness contrast is also pres-

ent, for the white square in the black surroundings appears brighter than the larger white square.

245. *Theories of color-vision.* The process of vision involves the physical causes, the physiological retinal processes and the psychological elements in the experience of visual sensations. Color-vision is largely physiological and psychological. To explain the mechanism of color-vision various hypotheses have been presented. The older theories were without any, or at best but little, anatomical basis. None of them is satisfactory in character; any theory of vision to be satisfactory must explain the physiologic process of vision, color-vision and the nature of perception, and thus far no one has been able to present anything more than a working hypothesis on any of these three most important factors.

246. *Young-Helmholtz theory.* Thomas Young is credited with the conception of the three-color theory. This lacked experimental foundation until after the work of Helmholtz. Young explained his hypothesis as follows:—"It is certain that we can produce a perfect sensation of yellow and blue by a mixture of red and green light and of green and violet light. There are reasons for supposing that these sensations are always composed of a combination of separate sensations. We shall proceed, therefore, to consider white light as composed of a mixture of these colors only, red, green and violet."

In this theory it is postulated that each nerve fiber of the retina is composed of three sub-members or fibers each of which is provided with a special terminal organ (a photo-chemical substance). An irritation of the first fiber supposedly produces a violet sensation, an irritation of the second fiber a green sensation and of the third, a red sensation. These three are the primary or principal sensations giving rise to the principal colors. An irritation, then, of the red and green sensation fibers would produce yellow, and so on through the color scale. White is produced by the simultaneous irritation of all three fibers; no irritation of any of the fibers gives the sensation of black. Young explained color-blindness as due to the lack of one or more of the fibers, the remaining process being assumed to be "redistributed" to some extent. This theory has some advantages in explaining cases of red and green color-blindness by assuming the absence of the corresponding process and, if necessary, a slight modification of the two remaining ones. It fails to explain total color-blindness, however. It likewise must meet the demand that by the proper mixture of three spectral colors all existing hues and degrees of purity can be reproduced; this is found to be impossible. Likewise, according to Young,

the color table must be triangular in shape but Maxwell's observations have shown that this cannot be the case.

247. Helmholtz modified Young's original hypothesis by assuming that each spectral color irritated all these fibers at once but in a different degree. Thus the red rays would irritate one fiber strongly and the other two feebly. The impression produced by spectral red would, therefore, also contain white and hence this impression is not the purest sensation which we can have. It has been found possible by Koenig, Maxwell, Abney and others, by studying the color sensations of normal eyes and of color-blind persons, to draw three curves showing the sensitiveness of the three primary sets of nerves to stimulation

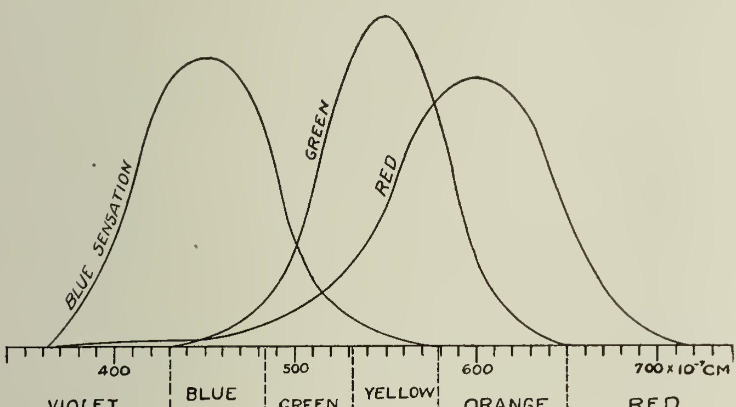


Fig. 140.—Curves Showing the Sensitiveness of the Three Primary Sets of Nerves (according to Young-Helmholtz theory) to Stimulation of Light of Different Wave-lengths.

by light of different wave-lengths. Such a set of curves as obtained by Abney is shown in Fig. 140. The scales of the curves are so chosen that when the ordinates intercepted on all three curves are equal the colors of wave-lengths corresponding to the abscissæ produce the sensation of white in the case of a normal eye. It will be noticed that the sensation of red can be stimulated by light of all wave-lengths between 4,000 (violet) and 6,900 (red) Angstroms. The sensation of green is stimulated by light of wave-lengths between 4,300 (blue) and 6,600 (orange-red). The sensation of blue is stimulated by all radiations between the extreme violet end of the spectrum to 5,900 (yellow). These results have afforded strong support to the Young-Helmholtz theory. This theory, then, explains the main facts of color-vision; there is as yet, however, no anatomical evidence of the existence of the three substances or sets of nerves; many of the observed facts in

the study of after-images are only approximately reconcilable with this theory; the problem of simultaneous contrast is not satisfactorily explained.

248. *"Duplicity" theory of von Kries.* The name of von Kries is chiefly associated with the duplicity theory which attempts to differentiate colorless and color-vision. This theory is based upon the anatomical evidence which we possess of the existence of rods and cones in the retina. The rods are assumed to be largely responsible for the sensation of light at twilight illumination and to be more responsive to the shorter wave-lengths of light; that is, they are responsible for our achromatic colorless sensations. The cones presumably respond only under stimulation by brightnesses represented by the range between maximum luminous conditions and twilight illumination and are not greatly increased in their sensitiveness by dark adaptation; they are responsible for both achromatic and chromatic sensations. Anatomical investigations show that the cones alone exist at the very center of the retina, the fovea centralis, and that the rods are present just outside this region and predominate in the outer retinal regions or zones. The chief facts which this theory successfully explains (since, parenthetically, it may be said that the theory was built in the main from these facts) are: (1) decreased sensitivity of the fovea in twilight, (2) colorless vision over the whole retina in dim light such as moonlight, (3) the shift in the maximum of the luminosity curves of the eye (the Purkinje effect) at low illuminations, (4) the absence of such a shift for foveal vision, (5) no achromatic threshold for red light is found for any region of the retina, (6) no achromatic threshold is found for any light in foveal vision and (7) colorless vision occurs over the whole retina in cases of total color-blindness. Other supporting evidence is the similarity of the luminosity curve of a totally color-blind person at ordinary illuminations to the curve obtained for a normal eye for twilight vision.

249. *Hering theory.* Hering assumed that there are six fundamental sensations, coupled in pairs; white and black, red and green, yellow and blue. To account for these six fundamental sensations he assumes the presence in the retino-cerebral apparatus of three distinct substances. Red light, for example, acts on the red-green substance causing a katabolic change or disassimilation which produces the sensation of red; the green light on the contrary would cause an anabolic change in this substance by its action, or assimilation, which would produce the sensation of green. The same phenomenon takes place in the case of the yellow and blue rays in relation to the yellow-blue substance. Intermediary rays act on the two substances alike. The

building up of the black-white substance causes a sensation of blackness and the breaking down of the substance gives a sensation of whiteness. A favorite argument in support of this theory is the observed fact that yellow appears to be a primary color because there is no simultaneous suggestion of both red and green in a yellow made by mixing these two colors. Many phenomena of after-images agree with this theory. If the eye be stimulated, for instance, by blue rays, anabolism will take place in the yellow-blue substance and an accumulation of the substance results. If, then, yellow light stimulates the same retinal area the breaking down of the yellow-blue substance proceeds at a greater rate and the sensation is greatly augmented. On the other hand, yellow decreases the amount of substance and increases the rate of anabolism under the subsequent stimulation of blue rays. Positive after-images are explicable by assuming that the process of anabolism or katabolism continues for a brief period owing to chemical inertia.

250. *Koenig's theory.* Arthur Koenig exploited a theory which may be considered a development of that of Young-Helmholtz. Red, green and blue are his primary colors. The decomposition of the retinal purple into yellow produces the weak sensation of gray, which causes any color when it is sufficiently weak. Further decomposition produces the sensation of blue. Perception of the two principal colors, red and green, is affected by the agency of the pigment cells. The cones are considered as dioptric instruments for concentrating the light on the epithelial layer.

251. *Ladd-Franklin theory.* This is one of the more modern theories. A primitive, photochemical substance, which is composed of numerous gray molecules, is assumed as being responsible for the colorless sensations of white, gray and black. These molecules exist in the primitive state only in the rods but upon dissociation they cause the colorless sensations. The gray molecules in the cones undergo development and only a portion of the molecule becomes dissociated by rays of a given wave-length or color. Three stages are postulated in the evolution of the gray molecule and are shown in Fig. 141. In the first stage the gray molecule is so constituted that it becomes broken up or disintegrated by light of all colors, thus producing a white or gray color sensation. In the second stage the molecule is more complex and contains two groupings. The dissociation of one or the other of these causes a yellow or blue sensation respectively. Their simultaneous dissociation produces white or gray. This stage is assumed to exist in the peripheral regions of the retina where red and green cannot be perceived as being such. In the third stage the yellow grouping is

divided into two new combinations, the dissociation of one of which produces a red sensation while a similar process in the other gives a green sensation. If, then, the red and green are dissociated together simultaneously, a yellow sensation results while the red, green and blue stimulated together produce gray.

252. The essentials of this very important development theory of color are given by C. Ladd Franklin in an essay on **Color-vision, Theories of,** in Vol. IV, page 2499 of this *Encyclopedia,* to which the reader is referred.

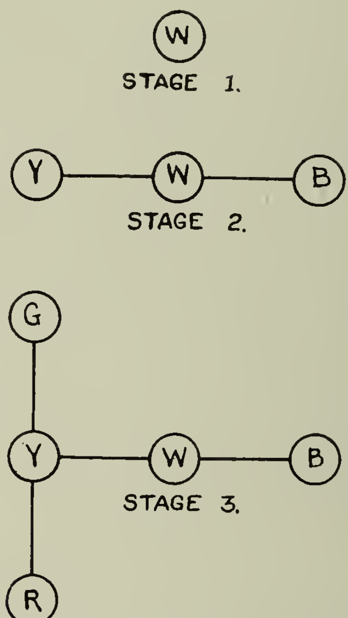


Fig. 141.—Illustrating the Ladd-Franklin Theory of Color Vision.

253. *Edridge-Green theory.* The retinal purple was discovered by Boll in 1876. This discovery gave rise to hopes that a photochemical theory of vision would explain the observed facts inasmuch as it was known that the visual purple was sensitive to light. If one examines the eye of an animal which has been left in darkness for some time before enucleation it will be found that the external segment of the rods has a purple color which vanishes quickly under the influence of light, assuming a yellow tint. The cones do not have this color and the fovea, which is composed of cones only, is without color. Kuehne labored with the question of the function of the visual purple, studying particularly the chemical properties of the retinal purple and

yellow; after his elaborate work the visual purple lost much of its significance in explaining the phenomena of vision. The yellow appearance which the purple retina assumes under the influence of light to which reference has just been made is supposed to be due to the formation of another pigment, the visual yellow. Many attempts have been made to find a relationship between the retinal purple and the vision of certain colors and with the adaptation of the retina to feeble light. Edridge-Green has recently done so; he assumes "That the cones of the retina are insensitive to light but sensitive to the change in the visual purple. Light falling upon the retina liberates the visual purple from the rods and it is diffused into the fovea and other parts of the rod and cone layer of the retina. The decomposition of the visual purple by light chemically stimulates the ends of the cones (probably through the electricity which is produced) and a visual impulse is set up which is conveyed through the optic nerve to the brain." Edridge-Green further assumes that "The visual impulses caused by the different rays of light differ in character just as the rays of light differ in wave-length. Then in the impulse itself we have the physiological basis of the sensation of color." It is also assumed that "The quality of the impulse is perceived by a special perceptive center in the brain within the power of perceiving differences possessed by that center or position of that center. According to this view the rods are not concerned with transmitting visual impulses but only with the visual purple and its diffusion."

254. *The Troland hypothesis.* Two of the most recent and noteworthy attempts to explain visual response in general and color-vision in particular are due to Troland (*American Journal of Physiology*, Vol. XXXII, 1913) and to Houstoun (*Proceedings of the Royal Society*, London, Series A, Volume 92). We shall in the succeeding paragraphs present some of the essential features of these two hypotheses.

Troland argues that most of the extant theories of visual response,—e. g., those of Hering, Donders, Mrs. Ladd-Franklin, etc.—err in a quantitative rather than qualitative way; "They are on the right track but have failed in progressiveness" since they involve vaguely or else not at all "The fundamental concepts and principles of modern theoretical physics and chemistry. . . . Most of these are not only vaguely formulated and contain no distinct reference to general physics and chemistry—to say nothing of the special physical chemistry of light and of nervous response—but they often flatly contradict both physical and physiological principles. The physical conception of *resonance* lies at the bottom of practically all of the hypothetical

accounts which have been given of the processes of visual stimulation; but it requires only a very simple calculation to show that if any microscopically observable structure is to resonate in tune with even the largest light waves the material substance involved must possess a modulus of elasticity two hundred million times greater than that of hard drawn steel. This is a *reductio ad absurdum* of all theories of mechanical stimulation which depend upon resonance.'' A second very vital objection is that light can act directly only upon electrical and not upon neutral mechanical structures; this leads us from mechanical to chemical hypotheses and from molar to molecular systems in which it is possible that the systems are of the right order to make possible selective response. We may, therefore, believe with Troland that the ''Ultimately successful doctrine as to the nature of the visual mechanism must involve the concept of electricity due to the fact that light is an electromagnetic process and consequently can react only with electrical or magnetic systems, as well as by the facts of retinal and general nerve physiology, which all point to electrical factors in stimulation.'' We shall have occasion to point out in some detail, under the succeeding caption, the general explanation of the mechanism of visual stimulation and visual impulses as outlined by Troland.

255. This investigator comes to the conclusion that there are in the retina *five* distinct visual substances; M_r, M_g, M_b, M_y and M_w: these are designated as *molecular resonators* because they are selectively ionized by lights of specific and differing wave-length or frequency and their intrinsic positive ions, I_{r+}, I_{g+}, I_{b+}, I_{y+} and I_{w+} are the exact psycho-physical correlatives to the visual qualities R, G, B, Y and W respectively. A study of the modes of occurrence of the fundamental attributes of *S*, the elementary visual sensation, reveals the following correlations: (1) if $g > o$, $r = o$; (2) if $y > o$, $b = o$ and conversely (3) if $r > o$, $g = o$ and (4) if $b > o$, $y = o$. In other terms, the hues R and G, Y and B are mutually exclusive or ''antagonistic''. The hues when arranged in the cyclic order

$$\begin{array}{ccc} & B & \\ R & & G \\ & Y & \end{array}$$

are such that adjacent qualities will fuse while opposite ones exclude or cancel each other. The attribute W (white) can be added to any possible combination of hues, while B is present in strict proportion to the absence of R, G, Y and W. In order, therefore, to take into account the ''antagonistic'' relations it is necessary to postulate the

existence of what may be called the *complementation* substance within the large ganglion cells of the inner stratum of the retina. The complementation molecules are made up of a nucleus and two side-chains. These side-chains are each a negative ion, the nucleus being doubly charged and positively. "Of these molecules there are two varieties. The first is so constructed chemically that its two negatively charged ionic side-chains are capable of combining simultaneously, but not separately, with the two positive ions of the visible impulse: I_{r+} and I_{g+}. The second reacts in a similar way with the visual ions: I_{y+} and I_{b+}. The result is that in each case the positively charged nuclei of the molecules are set free and become a part of the impulse

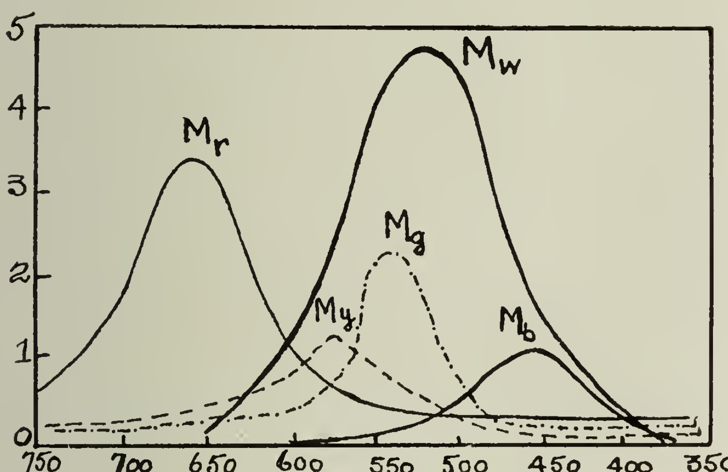


Fig. 142.—Curves Illustrating the Troland Theory.

as it is passing through the ganglion cells." These two substances may be spoken of as the R — G — complementation substance and the Y — B — complementation substance.

Fig. 142 contains five curves which represent the maxima into which the five specific molecular resonators are broken down by light waves of varying frequency. They are theoretical curves and represent what Troland speaks of as resonance functions of the specific substances M_r, M_g, M_b, M_y and M_w; the exact shapes may vary widely under alterations in the concentrations of the resonators, the intensity of the light and so forth. For stimuli of high intensity these curves will all be flattened owing to the concomitant action and influence of the forces expressed in Fechner's law.

256. It is very reasonable to suppose that the number of ions leaving

a retinal element via the neuro-fibrillæ per seeond is proportional to the number present or to the eoneentration, and it is quite apparent that what may be designated as the intensity of the impulse, or the number of ions passing through any eross-seetion of the nerve fiber per unit of time will depend upon the number leaving the retinal element and the number lost in the proeess of eonduetion. Let the impulse intensity be represented by the letter "i." "If, then, the impulse before passing through the ganglion eells has the eonstitution: $i_r + i_g$ where $i_r > i_g$, the eonstitution after passing these cells will be: $(i_r - i_g)$ of $I_{r+} + 2i_g$ of I_w" (in which I_{r+}, and so forth, represent the intrinsie positive ions whieh are the exact psyeho-physieal eorrelatives of the fundamental visual qualities R, G, B, Y and W respeetively). "The eorresponding sensation, S, will be a pink, not a greenish-red." Likewise it is obvious that when $i_r = i_g$ and $i_y = i_b$ the only impulse eomponent reaehing the eortex will be i_w; these are the eonditions for eomplete eomplementation. All of the familiar effeets of "eolor mixture" are represented in Fig. 142. For example, suppose the same eone is stimulated with lights of $\lambda = 6{,}500$ and $\lambda = 5{,}500$; with appropriate intensities the two elements i_r and i_g will eancel each other leaving only the i_y (and i_w) whieh is also introdueed by both lights. The eonstitution of the resultant sensation will be $S = Y + W$, although red and green lights have been mixed. The diagram (Fig. 142) also explains, aeeording to Troland, the faet established by J. J. Müller and von Kries that when a heteronymous light stimulus is made up of two (or more) lights having wave-lengths falling between the limits of $\lambda = 7{,}600$ to $5{,}670$ or $\lambda = 3{,}900$ to $4{,}920$ the *chroma* of the indueed sensation does not differ from that of a sensation indueed by a homogeneous wave yielding the same hue. It also explains the loeation of points of least ehroma and greatest luminosity in the visible speetrum at $\lambda = 5{,}750$ (approx.) and $\lambda = 5{,}000$; at these points the M_r and M_g, and M_y and M_b eurves, respeetively, interseet and henee with these lights the eomplementation reaetion finds its maxima.

Another important phenomenon this theory aeeounts for is the disappearanee of hue with inereasing light intensity. Every light stimulus supposedly aets upon every moleeular resonator but at low intensities a light of $\lambda = 6{,}550$ (say) aets very strongly only upon M_r and very weakly upon M_g, M_y and M_b; but as the intensity is inereased the inerease of the several eomponents of i (ions at the retina) follows Feehner's law (q. v.) and henee eaeh of these eomponents approaehes a definite maximum. The net result would be that, whatever the wave-length of light may be, its effect upon the several resonators at very high intensities is the same. The eurves of Fig. 142 also aeeount

for the repetition of the hue R in the violet end of the spectrum; extant visual hypotheses—except that of Hering—are at fault because of their inability to explain the repetition of the hue R in two widely separated parts of the spectrum.

257. *Houstoun's theory.* In his paper on a Theory of Color Vision Houstoun has attempted to explain the facts of color mixing by a theory which does not depend upon primary color sensations. The theory is, in part at least, a mathematical formulation of Edridge-Green's views; the portion which deals "with the retinal process applies ideas already more or less familiar, while the second part, which deals with the cerebral process, uses an idea quite original in its applications to color vision."

Fig. 143 (A) represents by the full line the sensitiveness of the eyes for light of different wave-lengths as determined by H. E. Ives from observations on about twenty persons viewing a surface having an illumination of 25 meter-candles with the pupils at normal apertures. The eye has, therefore, a maximum of sensitiveness in the green and falls off rapidly on both sides toward the red and violet. To what is this due? "The most obvious explanation is to *suppose* that there exist in the eye a very large number of vibrators, *with a free period in the green,* and that these execute forced vibrations under the influence of the light wave. The amplitude of the forced vibrations is a maximum when the free period of the vibrators coincides with the period of the incident light." The motion of one of these vibrators may be represented by the equation

$$\frac{d^2x}{dt^2} + h\frac{dx}{dt} + n^2x = E \cos at \text{ .... } (1)$$

in which x represents the displacement of a typical vibrator from its position of rest and $E \cos at$ is the force per unit mass exerted on it by the incident light wave. The symbol "a" represents the frequency and is equivalent to $\frac{2\pi e}{\lambda}$ in which "λ" represents the wave-length involved and "e" the velocity of light. The rate at which energy is absorbed by the vibrator is given by

$$E\frac{dx}{dt}\cos at \text{ .... } (2)$$

The solution of equation (1) consists of two parts, the free vibration and the forced vibration: when a vibrator is left to itself the free vibrations die down but are renewed under excitation. It can be mathematically shown that when the part of $\frac{dx}{dt}$ due to the forced vibration is calculated and substituted, equation (2) becomes ultimately as to its mean value

$$\frac{E^2 h\alpha^2}{2 \quad (n^2 - \alpha^2)^2 + h^2\alpha^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

"The intensity of the incident light is proportional to E^2. If it is assumed that the luminosity is proportional to the energy absorbed, and omit a constant factor, the ratio of absorbed to incident energy or, in other words, the visibility of radiation, is proportional to

$$\frac{\lambda^2}{(\lambda^2 - a^2)^2 + b^2\lambda^2}$$

This expression is graphically represented by the dotted line in Fig. 143 (A) for $a = 0.10\mu$. As a whole we may say that (3) represents the visibility curve roughly."

258. Equation (3), however, shows that, as E^2 is increased, the value of the equations remains constant. This is contrary to experience as expressed in Fechner's law that

$$\frac{dI}{I} = \text{constant}$$

(in which I represents the intensity of the light stimulus). Hence it is necessary to assume that the energy absorbed is proportional to $\frac{d(E^2)}{E^2}$: under this assumption it can be mathematically shown that the number of vibrators diminishes as E increases except for small values of E. Hence, this assumption implies that some of the vibrators go out of action when E^2 is increased. "When the energy of the vibrator reaches a critical value, the force attaching the vibrator to its center snaps, the latter then ceases to absorb light energy and a

chemical change takes place. This critical value is not the same for all the vibrators, but varies from vibrator to vibrator.'' We have here, it seems to the writer, the fundamental principle of the so called ''Quantum theory'' applied to explain visual phenomena. (See Planck's *Radiation Theory*, trans. by Masius.) According to this conception energy, E, is radiated in discrete or definite units and is connected with the frequency, v, and the universal constant, h, through the equation

$$E = n\,h\,v.$$

The detachment of one, two, three and so forth (n) electrons will give rise to varying quantities of radiation, which are multiples of a definite energy unit.

259. By way of further explanation Houstoun writes:—''Of course we are not to suppose that if E is constant the same identical vibrators remain in action all the time, but that there are two processes going on in opposite directions which balance one another, visual purple being bleached and constantly restored. When E increases, the point of equilibrium is shifted. Owing to the bleaching and restoration of the visual purple we must suppose the vibrators to be in a perpetual state of agitation. Their free vibrations are constantly being renewed. If the intensity of illumination is reduced, it is found that the visibility curve undergoes a change. Its maximum is gradually shifted toward the green, reaching the limiting position of 0.50μ when the intensity is very small, the curve becoming at the same time narrower near the maximum. The phenomenon is known as the Purkinje effect.'' * * * ''According to von Kries, the effect can be explained by assuming that the rods in the retina are chiefly responsible for vision at low intensities and the cones for vision at high intensities. I do not, however, think it necessary to assume two different mechanisms. We can explain the effect with one system of vibrators in either of two ways. First, we may suppose the vibrators embedded in a medium with a yellow color, something like potassium chromate. At low intensities the energy is absorbed near the surface of the medium: at high intensities most of the vibrators near the surface will have become bleached. Consequently a larger proportion of the energy is absorbed at a greater depth, but the energy on the blue side of the maximum suffers a greater absorption by the medium on the way in, and there is not so much left for the vibrators to absorb at this depth. Thus the maximum of absorption is shifted toward the yellow. I do not know the exact color of the yellow spot in the eye and am unable to say whether it would produce the required effect. The alternative explana-

tion is to assume that all the vibrators have not the same period, but that the value of a varies from vibrator to vibrator, $a = 0.55\mu$ being only a mean value. Then, if those that decompose more easily have a smaller value of a, the shift is explained. This explanation seems to me to be the better one. The assumption of different values of a follows naturally from the assumption that the vibrators decompose at different intensities. Also, Ives' visibility curve [the full curve in

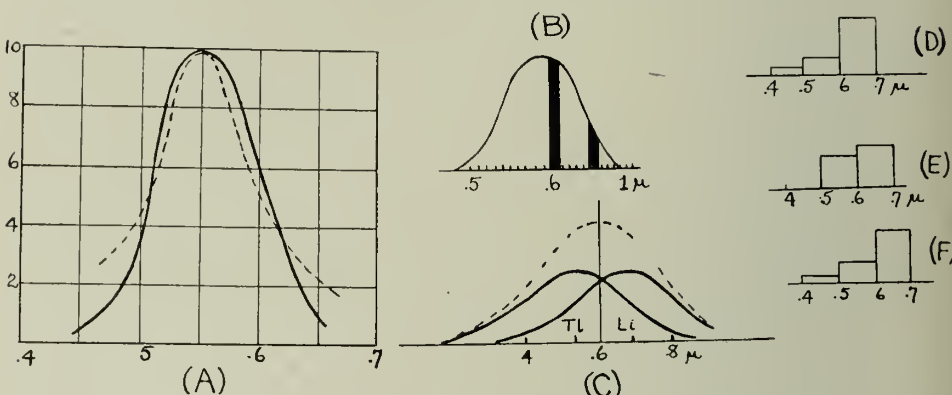


Fig. 143.—Curves Illustrating the Houstoun Theory.

(A) Representing the sensitiveness of the eye to light of different wave-lengths.

(B) Distribution of energy over the different waves set up in the nerve, produced by yellow light of wave-length 5900 t.m.

(C) Energy curves of equal luminosity to represent lithium red and thallium green and their sum as shown by dotted line.

(D-E-F) Luminosity curves representing respectively a sodium yellow, a lithium green and a white light.

Fig. 143 (A)] is very like a probability curve, i. e., it looks as if it could be represented by the expression

$$e^{-k(\lambda - 0.55)^2}$$

where k is a constant. If the different values of a are distributed around the mean value according to the law of error, the visibility curve will be the sum of a great number of small curves of the type represented by (3). If these component curves have the same value of b, their individual peculiarities will not appear in the resultant, but only the law according to which they are grouped about their mean, and hence we shall obtain an expression similar to (4) for the resultant. By proceeding in this way we can obtain a much better agreement between theory and experiment than in Fig. 143 (A)."

"There is no decided evidence in favor of three classes of vibrators,

i. e., the visibility curve has not three separate maxima. It has a simple form, probably simpler than the three component visibility curves into which it would have to be resolved to meet the views of those who believe in the existence of three independent primary sensations with an independent mechanism for each."

260. Houstoun supposes in regard to the cerebral processes that the vibrators set up waves in the nerves and that these nerves carry these waves to the brain somewhat after the analogue of the telephone. There is one important difference, however, and this is that the vibrator in vision does *not* reproduce the light wave exactly owing to its being subject to too many disturbances. A monochromatic wave is not, therefore, transmitted along the nerve in a manner such as to preserve its monochromatic character. Or again, the vibrator may start from rest having its free and forced vibrations superimposed. "The free vibration may die down, then be renewed again by an impact: the period of the vibrator may change slightly. The vibrator may then decompose and, after a short rest, reunite and start again. Now an irregular motion of this sort may be regarded as due to a superposition of sine waves, i. e., the displacement of the vibrator may be expressed as a Fourier integral."

261. We may suppose that, with yellow light ($\lambda = 5{,}990$ Angstroms) falling on the retina, the distribution of energy over the different waves set up in the nerve is represented by Fig. 143 (B). The whole area of the curve represents the energy received by the brain or the luminosity of the sensation. The maximum of this curve will coincide with the wave-length of the incident light but the curve will not in general be symmetrical, since more of its area will be on the same side as the maximum of the free vibrations. Furthermore, the area of the rectangular strip at 0.60μ shows twice as much energy included as in the area 0.65μ. If the vibrator executed a pure forced vibration for a very long time, the curve would be infinitely narrow. The breadth of the curve is thus a measure of the degree of disturbance to which the vibrator is subject. Three qualities are associated with a light impression, namely luminosity, hue and saturation: the area of the curve represents the luminosity, the position of the maximum the hue and the narrowness of the curve the degree of saturation.

262. The phenomena of *color mixing* may be readily explained by such curves. Fig. 143 (C) shows two energy curves of equal luminosity representing lithium red and thallium green compounded as one as shown in the dotted line with a maximum at 0.60μ.

263. "But, it will be asked, how does this theory explain the apparent trichromatism of our ordinary sensations? We here must fall

back upon the reason given by Edridge-Green, namely that the color-perceiving center in the brain is not sufficiently developed to discriminate between the character of adjacent curves. Two curves must be widely different in shape and position, before the color-perceiving center can detect the difference. A curve has an infinite number of points on it. The color-perceiving center is so badly developed that, as far as it is concerned, the curve is sufficiently specified by three points on it, provided that these points are distributed over the spectrum. We can therefore represent our energy curve by three points. Since the sensation of luminosity is better developed than that of color, I have preferred to represent the curve by three rectangles as in the Fig. 143, (*D*), (*E*) and (*F*), which represent respectively a sodium yellow, a lithium green and a white light, all of equal luminosity. The area of the rectangles may be regarded as the amount of stimulation of the three primary sensations of the Young-Helmholtz theory: indeed, I took the value of the ordinates from one of Sir William Abney's curves, merely exaggerating the size of the third component in diagram (F) to make it visible. The diagrams may therefore be regarded as a means of representing the results of the Young-Helmholtz theory. I believe, however, that they are more than this: that they actually are energy curves—crude ones. it is true, but sufficiently representative for the discriminating power of the color-perceiving centers. * * * The diagrams are, to some extent, a connecting link between the Young-Helmholtz theory and that of Edridge-Green."

XVII. LIGHT STIMULUS AND RETINAL CURRENTS

264. The effect of the stimulus of light on the retina is perceived by the brain as a visual sensation. The process or processes by which the ether-wave disturbance causes this visual impulse is still very obscure. As a matter of fact the whole of the field of photo-chemical action is still in its infancy. The process of making an ordinary negative by exposing a dry plate in a camera to light and the manner of developing and fixing such a plate are mechanically easy of accomplishment. But ever since the discovery that an invisible light effect could be developed into a strong image by the application of suitable reducing agents, the constitution of the invisible or so-called "latent image" has been the subject of study and controversy and no wholly satisfactory explanation of the effects of radiation upon silver salts has been presented. The process by which the ether disturbance causes a visual impulse may be ascribed to (1) chemical action, (2) molecular strain and (3) electrical action.

265. According to the *chemical theory* it is presumed that certain visual substances in the retina are affected by light and that vision originates from the metabolic changes produced in these visual substances. It is supposed that the metabolic changes consist of two phases; the upward, constructive or anabolic phase and the downward, destructive or katabolic change. These anabolic and katabolic changes in various visual substances are supposed to produce the variations of sensation of light and color. This theory is complex. Numerous objections have been urged against its acceptance; for it is difficult, for instance, to see how this very rapid visual process can be due to a comparatively slow chemical action consisting of the destructive breaking-down of the substance followed by its renovation. Support was at first furnished the chemical theory by the bleaching action of light on the visual purple present in the retina, but it has been discovered that the presence or absence of visual purple is not essential to vision and that its presence is of only secondary importance. For it is well known that the visual purple is lacking in the fovea centralis and it is also found to be completely absent from the retinæ of many animals possessing keen sight.

Writing in the *Ophthalmic Review* during 1916 Edridge-Green states his belief as to the nature of retinal stimulation. He says:—"A ray of light impinging upon the retina liberates the visual purple from the rods and a photograph is formed. The rods are concerned only with the conveyance of the light impulses to the brain. The ends of the cones are stimulated through the photo-chemical decomposition of the visual purple by light, and a visual impulse is set up which is conveyed through the optic nerve fibers to the brain. The character of the stimulus and impulse differs according to the wave-length of the light causing it. In the impulse itself we have the physiological basis of the sensation of light and in the quality of the impulse the physiological basis of the sensation of color."

266. The *mechanical theory* depends, in large measure, upon the theory of resonance in connection with chemical action. It is readily conceivable that a ray of light can cause a chemical decomposition of a substance in which the rhythmic excursions of an atom or atoms from the center of attraction in a molecule are in exact tune with the waves of light falling on such atoms. The excursions may be so increased in extent by the rhythmic energy supplied by the light waves that the atoms will leave the parent molecules and produce new molecules. It is not as easy to see why the rhythmic excursions of atoms in the same molecule are also increased to the point of molecular rupture when the wave-motion of the impinging rays is not exactly

in tune. But some photographic and mechanical examples help us out. For if a sensitive salt, such as silver chloride, is exposed to the action of the spectrum, we can plot a curve showing the sensitiveness of this particular salt to the different spectral rays. Such a plotted curve shows a rise in sensitiveness to a maximum followed by a decline; the maximum of such curves shows the place in the spectrum where the vibrations causing the ray are in tune with the vibrations of the chlorine atom in silver chloride for example, the chlorine being that part of the molecule which is swung away and annexed to some other adjacent molecule. We have also mechanical examples of the effects produced by vibrations which are not in tune with, but which act upon, a vibrating body. A simple apparatus consists of two different pendulums which can act upon one another through a proper communicating medium; such would occur, for example, when the pendulums are connected to a taut piece of rubber tubing fastened horizontally. When the pendulums are of equal length and one is started into vibration, the second one also begins to swing and, since it is in tune, the amplitude constantly increases. But if one pendulum is a little longer or shorter than the other, experimentation shows that one pendulum causes the second one to swing with increasing amplitude and by degrees the two will swing in opposite directions; the amplitude of the first pendulum will decrease and finally come to rest when the motion starts out again as at first. Thus, if the mechanical analogy is applicable here, it is seen that if the waves causing a ray of light are out of tune with the vibrations of the atoms the amplitude will still be increased and the increase can be such as to swing the atom beyond the sphere of molecular attraction and so decompose the molecule but with less ease than when the waves are in tune.

267. We have written of the *resonance theory* as a correlation and interaction between radiant energy and the atom of the molecule and have thus followed and outlined the theory as it is generally presented. However, in the light of modern physics, we should presumably have written of *resonance* and *electrons*. In fact, the essential points in the mechanical theory of retinal stimulation as consisting of resonance effects coupled with chemical action fit in with many of the physical phenomena known as "*photo-electric* actions." This term includes phenomena due to the action of light in liberating negative electrons from various metallic substances. It is known, for example, that there is a considerable influence of the wave-length or frequency of the light upon the number of electrons emitted and that curves plotted between frequency and rates of "leak" of negative electricity from metals such as sodium, potassium and rubidium show maximum or

resonance effects. Likewise, salts which undergo decomposition in the light, such as silver chloride, are strongly photo-electric. We are, therefore, presumably dealing under the tenets presented to us in this theory with the expulsion of electrons due to resonance; the electrons are set in resonant vibration by the incident light and acquire sufficient velocity to enable them to escape from the atom. The student of physiologic optics who is interested in this great unsolved problem of the connection between light and retinal stimulation will do well to peruse such a work as H. Stanley Allen's *Photo-Electricity*.

268. The *electrical theory* supposes that the visual impulse is the concomitant of an electrical impulse; that an electrical current is generated in the retina under the influence of light and that this is transmitted to the brain through the optic nerve. It is an undoubted fact that light gives rise to retinal currents and that, on the other hand, an electrical current suitably applied causes the sensation of light. Holmgren, Dewar, McKendrick, Kuhne, Steiner, Waller and others have shown that illumination produces electric variation in a freshly excised eye. The currents are very small in value, hence a very sensitive dead-beat galvanometer (having a figure of merit of about 1×10^{-10}) must be used. Currents of injury or contact potential differences arise when the galvanometer terminals are connected to the cornea and to the cut end of the nerve respectively. These may be compensated for by means of a potentiometer device. When a freshly excised eye, thus connected, is illuminated it is found that the current of response due to the action of light on the retina is always from the nerve, which is not directly stimulated by light, to the retina. Such currents have been designated as *positive* when flowing from the less excited to the more excited. The normal effect of light on the retina as noticed by the observers already mentioned is a positive variation during exposure to light of not too long duration. Cessation of light is followed by recovery. Deviations from this are regarded as due to abnormal conditions of the eye, rough usage, mechanical pressure and so forth. Unlike muscles, successive retinal responses exhibit little change; for, generally speaking, fatigue is very slight and the retina recovers quickly even under strong light if the exposure is not too long.

The *general experimental method* adopted in investigations on the retinal currents due to light stimuli is as diagrammed in Fig. 144. Contacts are made with the galvanometer G through non-polarizing electrodes with the cornea A and the cut optic nerve B. On making contacts and closing the circuit through the galvanometer a considerable current of injury will be found which must be compensated for

by the use of an auxiliary circuit CD attached at the points A and B. This auxiliary circuit consists of a battery short-circuited through a high resistance so arranged that any desired potential difference may be tapped off and applied to the eye at A and B in such a direction as to counteract the effects due to the current of injury. The eye is enclosed in a black box with an aperture through which light can be admitted when desired.

Historically, Holmgren is accredited with the initial experiments on the electrical response of the eye to stimulation by light. His work was published in 1866 (*Physiol. Untersuch, Heidelberg*, Bd. ii, page 81 and Bd. iii, page 358). He was able to demonstrate that when light was allowed to fall upon the eye of a frog that had been kept in the dark and, again, when the light was removed, there was an increase in

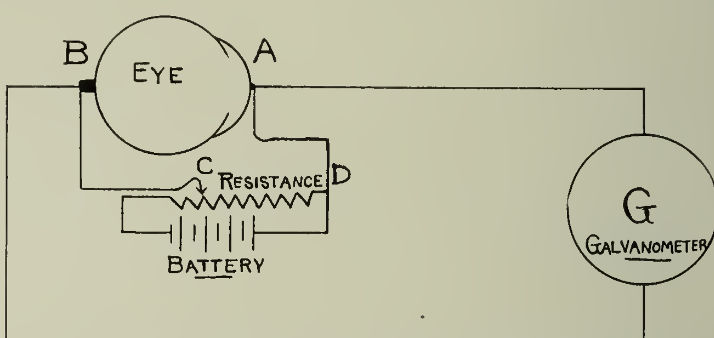


Fig. 144.—Scheme of Arrangements of Eye, Galvanometer and Compensating Potentiometer Device Used in Investigating Retinal Currents Due to Light Stimuli.

the positive direction of the current present during darkness. The strength of the current was, within certain limits, proportional to the intensity of the light. Likewise, the onset and removal of light was attended with the same electrical changes when the posterior half of the eyeball only was employed.

Independently of Holmgren, experiments on the physiological action of light were conducted by Dewar and M'Kendrick: their joint papers appear in the *Transactions of the Royal Society of Edinburgh,* Vol. XXVII, 1873. The conclusions to which these experimenters came are: (1) That the impact of light on the eyes of mammalia, aves, reptila, amphibia, pisces and crustacea, produces a variation of from three to ten per cent. of the normal electromotive force existing between the corneal surface and the transverse section of the nerve; (2) this electrical alteration may be traced to the brain; (3) that the rays which

we regard as most luminous produce the largest variation; (4) that the alteration of the electrical effect with varying luminous intensities follows the law of Fechner; (5) that the electrical alteration is due to the action of light on the retinal structure itself and (6) that it is possible to discover by experiment the physical expression of what is physiologically called fatigue.

Kühne and Steiner (*Physiol. Untersuch, Heidelberg,* Bd. iii, 1880) investigated the reactions of the isolated retina. They found that the electrical change on lighting and darkening is a complex one, the variation being positive, then negative, and finally again positive. The reaction is divisible, according to these observers, into two parts: the first, due to the onset and continuance of illumination, consists of a negative variation preceded by a positive; and the second, caused by the disappearance of the light, consists of a simple positive variation.

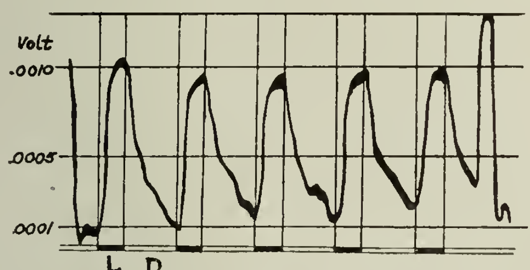


Fig. 145.—Photogram of Response to Light (and Recovery) in Frog's Retina. (After Waller.)

269. Waller has carried out a number of important researches in this field of investigation. A series of photograms of responses to light in the frog's retina is given in Fig. 145. These maxima represent five normal responses due to a candle at 2 feet with illumination for 1 minute and obscurity for 2 minutes respectively. The abscissæ represent the time in minutes and the ordinates the absolute electromotive forces. These results indicate rapid rises in electromotive force under illumination and less rapid recovery.

270. These retinal current effects can be imitated and their counterparts observed in non-organic substances. Considerable work on this subject has been done by Bosé. He took, for instance, a rod of silver which he beat out into the form of a hollow cup and sensitized the inside of this cup with bromine vapor. The cup was filled with water and connected through a galvanometer by non-polarizable electrodes. A current arose due to differences between the inner and outer surfaces of the cup; this was balanced by a compensating electromotive force.

This gave an arrangement somewhat resembling the eye, with a sensitive layer corresponding to the retina and a less sensitive rod corresponding to the conducting nerve-stump. The apparatus, being enclosed inside a black box, was illuminated through an aperture at the top; on exposing the sensitive surface to light the balance was at once destroyed and a responsive current of positive character produced. Upon cessation of light there was a fairly quick recovery. It is of interest to compare the response and recovery curves of the frog's retina as obtained by Waller and given in Fig. 145 with similar phenomena obtained by Bosé with his sensitized silver cell as shown in Fig. 146.

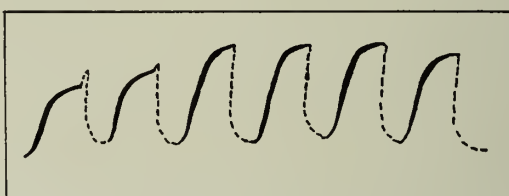


Fig. 146.—Curves Obtained with Sensitized Silver Cell Analogous in Form to Retinal Current Curves. (After Bose.)

271. The main conclusions to which Waller arrived in his work are:—

(a) A fresh normal eyeball manifests a positive current which gradually declines to zero and becomes reversed.

(b) On exposure to light the normal current, whether positive or negative, undergoes a positive variation.

(c) The magnitude of the response to light increases with the duration of illumination.

(d) The magnitude of the response to light increases with the strength of the illumination.

(e) Fatigue is less pronounced in the case of the retina than in that of muscle.

(f) Colored lights act in the same direction, and in accordance with their luminosity. No electrical evidence is obtained of antagonistic influence.

At the conclusion of one of his papers Waller says:—"I believe it to be proven by these observations that the retina is the seat of a double electrical movement, a simultaneous positive and negative effect, but whether the double effect is the expression of duplex change in one substance or of two changes in two different components cannot

be strictly demonstrated. I am of the opinion that we have to do with a duplex change, constructive and disruptive, in one substance."

Gotch (*Journal of Physiology*, Vol. XXIX, 1903 and Vol. XXXI, 1904) made use of a capillary electrometer which recorded the rapid alternations of current present in the response of the eye. This observer divided the electrical reaction of the eye to light into three portions: (1) The rise due to the sudden illumination, or the "on-effect": (2) the continuous change occurring during the continuance of the illumination, and (3) a second rise due to the sudden change from light to darkness, or the "off-effect." The photo-electric changes, he concludes, are all of the same general type, giving rise to monophasic effects and appear to be due to processes occurring in the posterior part of the eyeball. The results seem to indicate the localization of two photo-chemical substances in the posterior half of the eyeball, these being a substance reacting to light and a substance reacting to darkness. Each reaction is a change of the same type, but for the change to occur the eye must be previously adapted, i. e. the substances must undergo phases of metabolism under conditions opposite to those which evoke the reaction effects.

Einthoven and Jolly (*Journal of Experimental Physiology*, Vol. I, 1908) conclude that the form under which the photo-electric reaction manifests itself gives ground for the supposition that there occur in the eye three separate processes and that each of these may be dependent upon a separate substance. The *first* substance reacts more rapidly than the other two. On lighting, it develops a negative, on darkening a positive potential difference. The *second* substance reacts less rapidly than the first and in an opposite direction. Hence, on lighting, it develops a positive, on darkening a negative potential difference. The *third* substance reacts in the same sense as the second but much more slowly. For each of these substances the rule holds good that with moderate and strong lights the energy of the stimulus increases more quickly than the energy of the reactions. Furthermore, the latent period of the photo-electric reaction is in a high degree dependent upon the intensity of the stimulus. With strong stimuli it is of the order of 0.01 second, while with very weak stimuli it may be lengthened to more than 2 seconds. These values are in agreement with the latent periods of light perception in the human eye.

272. Some investigations, as yet unpublished, now being carried on by Sheard and McPeek upon the retinal responses to light of varying wave-lengths using enucleated dog eyes indicate that there is a positive increase of potential established by wave-lengths of light ranging from the extreme red to the green, reaching a maximum in the yellow

to yellow-green region and that there is a decrease or relatively negative potential established between the retina and the cornea under stimuli from green-blue to the lower visible limit. The form of curve established corresponds in a general fashion to the luminosity curve of an eye, positive potentials of increasing values being established after the cessation of stimulation up to the maximum in the green region and negative potentials resulting after the cessation of stimuli in the green to violet region. In all cases the zero of comparison was taken as that established under no light excitation and with such compensating electromotive force established across the eye from cornea to cut nerve as to produce a balance at the initial zero of the galvanometer scale. The current responses are, as stated by Waller, always initially positive in direction (from retina to cornea). This increase and decrease, or positive and negative, potential effect could be carried through a series of changes such that the retina was exposed in succession, followed by periods of rest of six minutes, to a certain wave-length and then to its complement. Interesting results have been obtained showing that practically no retinal potential changes occur, after the initial period of excitation by light of a particular spectral character, unless exposures are made in a region very closely approximating the complementary color and that when so exposed the potential is carried back approximately to the value which it possessed previous to the dual exposures. The writers are inclined, therefore, to the view that there is electrical evidence of antagonistic influences and of anabolic and katabolic processes such as those demanded in the Hering theory or in the hypothesis as to the mechanism of visual stimulation and the exact mechanism of the visual impulse as promulgated by Troland and outlined in the following paragraphs.

273. Troland bases his physico-chemical theory of visual response upon the fact that the mechanical hypothesis of visual response is untenable because the mechanical systems are not of the right order of magnitude to vibrate in unison with light and because molar systems do not carry the free electronic charges which are essential in order that the forces of light rays shall act upon them. There is, however, evidence that many, if not all, chemical molecules are electrical dyads made up of positively and negatively charged atoms or radicles which can be separated from each other by electrical forces. Consider a certain molecule M which is composed of positive and negative parts: I_+ and I_- respectively. Then, since the system is not rigid, the I_+ and I_- will be capable of vibrating with respect to each other with a certain frequency, n. If then n is also the frequency of some light ray impinging upon M, the molecule will resonate with

respect to this ray so that under proper conditions the constantly increasing amplitude of vibration will result in a final disruption of the molecule. I_+ and I_- in the free state are ions and the process initiated by the light is one of ionization. Hence, from these premises and from the general physical point of view, it is probable that *the immediate effect produced by light upon the retina consists in an increase in the ionization of certain specific chemical substances there present.* These substances, in general designated by M, are supposedly enclosed in the terminal segments of the rod and cone cells. The most successful hypothesis to explain the nerve impulse is that of W. Nernst (*Archiv. für die ges. Physiologie,* Vol. CXXII, 1908) as elaborated by Hill (*Journal of Physiology,* Vol. XL, 1910) and Lillie (*American Journal of Physiology,* Vol. XXVIII, 1911). In accordance with this hypothesis the stimulation of nervous tissue is conditioned by an increase in the ionic concentration of its native dissolved substances. Certain substances, then, contained in the terminal segments of the rods and cones suffer increased ionization under the influence of light and this increased ionization, via the mechanism of the Nernst hypothesis (*vide infra*) initiates the visual impulse. Troland, independently of Nernst, makes the following definite assumptions concerning the mechanism of the visual impulse. "(1) The visual impulse consists in the actual propagation of the positive ion, I_+, from the rod and cone cells along the optic nerve and tract to the cerebellum (especially to the neurons of the cuneus in the cerebral cortex). (2) This propagation takes place with the speed of the visual impulse and occurs within the neuro-fibrils which are thought of as *molecular tubes* within which it is possible for even single ions to travel without encountering great resistance. (3) The manner in which an individual ion may be imagined to be propagated is as follows: The non-fibular portion of the nerve fiber is made up of a mixtnre of substances, certain of which are ionized and others of which are capable of constituting an osmotic membrane which is normally equally permeable to positive and negative ions. However, when a positive ion comes into contact with one of the neuro-fibrils the surrounding neural substance acquires a slight differential permeability, so that the negative ions are capable of moving within it more readily than are the positive ions. This being the case, the loss of negative ions into the surrounding tissues—say into the myelin sheath when this is present—results in the development of a positive charge within the core. The original positive ion thus finds itself placed within the influence of a positive field. Since this is a state of disequilibrium, if the ion is free to move—and if, as will be the case, its charge is much smaller than

that produced in the nerve—it will travel in one direction or the other along the neuro-fibril. If we suppose the ion to have had an original impetus in the afferent direction, it will move in this sense. The resulting process is obvious. As soon as the ion has moved into a new region of the nerve fibril the permeability of the neural substances about it for negative ions will be altered as before, a new state of disequilibrium will be produced and the process will be repeated, the ion moving continuously in one direction within the fibril.'' The general nature of the visual cerebrosis, C, follows at once from the account of the mechanism of the impulse. *The cerebral state corresponding with any condition of retinal stimulation consists simply in the presence in the cerebral cells of the specific ions which are liberated in the retina by the action of the light.*

274. Writing on the electrical phenomena in the stimulated and non-stimulated eye, Troland says:—''We have supposed that the rods and cones of the retina are the seats of the production of an equal number of positive and negative ions and that, of these ions, the former are propagated along the optic nerve in the form of the visual impulse. It follows that the negative ions remain unneutralized in the bacillary layer. Since the state of ionization is not quantitatively zero even in the absence of all light stimulus, it follows that if we examine a fresh and even unstimulated eye we shall find the cut surface of the optic nerve to be positive with respect to the layer of rods and cones, the latter being negative. Experiment shows this to be the case. (See Rivers, W. H. R.: *A Text-book of Physiology.*) The fact that the inner layers of the retina are normally positive with respect to the cut surface of the optic nerve may be explained by supposing that there is a large *impulse loss* (of the positive ions) in the synapses of these layers. This corollary also accounts for the negativity of the outer as compared with the inner strata, and of the nerve as compared with the ocular media and cornea. When light falls upon the retina, our postulates demand an immediate increase in the ionization of the molecular resonators in the rod and cone layer, the consequence of which is an increase in the impulse intensity, an increased impulse loss in the synaptic strata and an increased positivity of the optic nerve endings. If the entire retina is illuminated, the first electrical effect will be an increase in the negativity of the bacillary layer, owing to the departure of a larger number of positive ions per element of time. The second electrical effect will be an augmented positivity of the synaptic layers, owing to the discharge of the above mentioned positive ions into this region. These ions will be in part picked up by the fibrils of the optic nerve fibers, with the

result that an increased positivity of the cut surface of this nerve will ensue. Coincident with this, however, there will be a still greater enhancement of the positivity of the ocular media and hence of the cornea, by virtue of the increased impulse loss. We expect, therefore, that the incidence of light at the retina will result in a positive variation of the current normally established between the cornea of the eye and the cut surface of the nerve and that with an injured retina this will be immediately followed by a negative variation. Both of these expectations are fulfilled by experimental data. When the stimulus is removed the flow of positive ions along the nerve will immediately decrease, but on account of its relatively large mass the

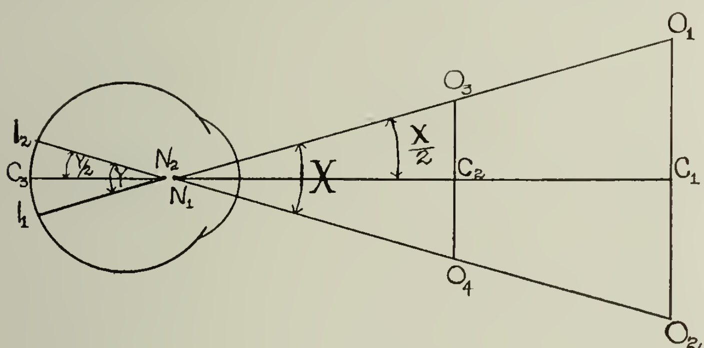


Fig. 147.—The Visual Angle.

charge of the ocular media will be only slowly lost; consequently the removal of the stimulus will effect a second 'positive variation' as shown by experiment."

XVIII. THE FORM SENSE

275. *Central visual acuity.* The perception of form or the visual acuity, properly speaking, is measured by the smallest angle under which the eye can distinguish the form of an object, or it is measured by the lowest angle under which two points can be distinguished from each other. The visual angle, X, Fig. 147, is comprised between the two lines which connect the two extremities of the object to the anterior nodal point of the eye; this angle is also equal to the angle Y which is formed by the lines connecting the extremities of the image with the posterior nodal point. By reference to the figure it will be seen that

$$\text{tangent}\ \frac{X}{2} = \frac{C_1O_1}{C_1N_1} = \frac{C_2O_3}{C_2N_1} = \frac{C_3I_2}{C_3N_2}$$

The principle of Giraud-Teulon states that "The acuity of vision of a subject is inversely proportional to the size of the minimum visual angle by which it can be impressed or affected." This minimum angle is modified and influenced chiefly by the luminous intensity, by the pupillary diameter, by the state of adaptation and by the retinal region which receives the image.

276. Astronomers have devoted considerable attention to this question of the visual acuity minimum. Hooke said that in order that a double star be recognized as such by an eye it is necessary that the interval correspond to one minute and that it would demand good eyes in order that such a recognition be made. Physiologists have made investigations using small gratings the bars of which were of the same size as the intervals; in a general way these were used for determining the maximum distances to which they could be removed from the eye before the bars and interstices became confused. The numerical results of these experiments made by such men as Tobias Mayer, Volkmann, Weber, Helmholtz and Bergman, in which gratings with various sized bars and intervals were used, vary from 51 to 94 seconds. It is, however, to be observed that it is neither the width of a bar nor that of the interval but the sum of the two which corresponds to the minimum visual angle as determined in these grating experiments. The minimum visual angle separating two points is commonly taken as one minute: a mathematical calculation (based upon the theory of the limit of resolution of a telescope) in which the radius of the pupil is taken as 2 millimeters, gives an angle of 42 seconds. If the calculation is made for the size of the retinal image corresponding to 1 minute there is obtained the number 0.0044 mm.,

since $\text{tangent } 1' = \dfrac{I_1I_2}{C_3N_2} = \dfrac{I_1I_2}{15 \text{ mms.}}$ (Fig. 147). The bacillary layer of the fovea centralis is made up of cones of about 0.002 mm. diameter. If, then, the least angle of visual distinction should correspond to the size of a cone we should have

$$\text{tangent } X = \frac{0.002}{15}$$

or the minimum visual angle would be about 30 seconds. Hence in the experiment of Hooke we may suppose that two stars can be distinguished if there is found a third cone between the two cones on which their images are formed; this third cone must evidently receive

no impression. It may, therefore, be concluded that the angular size of a cone must be smaller than the angular distance separating the two stars. In the experiment of Helmholtz, however, it cannot be said that the size of the cone must be smaller than the angular size of the black bar; but we can conclude that the cone must be smaller than the angular distance separating the centers of the two neighboring luminous intervals or smaller than the sum of the black bar and the luminous interval, for if the size of the cones were the same as this distance all the cones would receive the same quantity of light and the bars would be confused. At any rate, the visual acuity does not appear to reach the degree which would be expected according to the retinal structure and the reason is doubtless to be assigned to optic irregularities, sizes of diffusion circles and other similar sources of optical inefficiency. It is rarely likely, then, that a luminous point forms its image on a single cone; the varying results obtained from the various experiments on the minimum angle of visual distinction are, without doubt, partially dependent upon the perfection or imperfection of the eye in optical details. It might seem permissible to measure the form sense by finding the *least angle of visibility;* this would involve the determination of the smallest visual angle under which an object could be seen. But it is evident that this latter angle depends almost solely on the luminous intensity of an object for we see, for instance, fixed stars very well when they are sufficiently luminous in spite of their minimum angular size. If an eye were optically perfect so that the image of a star could be formed on the surface of a single cone, then the object would be made visible if the luminous impression were sufficiently strong even though the image did not occupy the whole of the surface of the cone. But stars are not seen as points; their images are circles of diffusion composed of more and less luminous portions; when the illumination is feeble these less luminous parts disappear and the stars appear smaller. The image, therefore, generally covers several cones; if the light diminishes the image may be formed on a single cone and the visibility then depends upon the brightness only.

277. The following is a description of an apparatus for the measurement of the central acuity of vision due to Burch. He says:—"Two fine wires about 0.1 millimeter in diameter are stretched across a pair of sliding frames furnished with a screw adjustment so that they can be set parallel to each other at any desired distance from contact up to 3 centimeters. The frames are mounted in a ring which can be rotated behind a circular aperture in a screen so that the operator can alter the direction of the wires without affording any

clue to the observer. A sheet of white blotting-paper is fixed at an angle of 45° a foot or more behind the screen so as to receive the light of the sky and serve for a white background against which the wires appear as black lines. Ascertain the maximum distance at which the observer can distinguish the wires when they are 2.5 to 3 cms. apart. To make sure that he really does see them the operator alters the direction two or three times. Call the distance *l* and the diameter of the wire *d*. Then $\frac{d}{l}$ equals the chord of the smallest angle of black upon white that produces a visible effect.'' But Burch goes on to remark that ''This does not measure the visual acuity. Owing to inevitable irregularities of refraction in addition to the errors of spherical and chromatic aberration, the image of a point is not a point but is spread over an appreciable area. And the wire is visible, not when its geometrical image is large enough to be discerned, but when the black of it mixing with the white, and spread over that area, makes a perceptible shade of gray.''

278. The visual acuity is measured in practice by the charts of Snellen or some similar device. The letters are constructed so as to be under an angle of 5 minutes when viewed at the distance for which they are marked; the lines which form the letters and the intervals which separate various portions of a letter (such as the letter **E**) are seen under an angle of 1 minute. The basis of the Snellen charts is, then, double the normal acuity as determined by the grating in which each bar and each interval corresponds to about a half minute. In order, therefore, to have a standard with which we can compare, with the least trouble, the vision of an eye with that of the assumed normal we use letters that are known to be recognizable at the proper distance by eyes whose $V = 1$; in other words, at such a distance that their lengths appear to fill the angle of 5 minutes and their breadth (each limb) the angle of 1 minute; this distance expressed in meters or feet is called *D*. The formula for visual acuity then becomes the one generally used, $V = \frac{d}{D}$ or, in words, the vision of an eye is equal to the distance *d* of the smallest recognizable letter divided by that distance *D* at which a *standard* eye ($V = 1$) ought to read the same letter. It is obvious that the letters which are intended to be seen at a distance of 12 meters, for example, must have double the linear size of those which are seen at 6 meters. If the former are seen at a distance of 6 meters only we have $V = 6/12 = 1/2$. In some respects,

however, this is illogical; Javal and other writers have pointed out that we should, in the above case, say that the acuity is $\frac{1}{4}$ since the surface of the letter in question is four times greater than that which corresponds to an acuity equal to unity. And, again, although it has been supposed that a normal eye has $V = 1$ as a minimum on the standard adopted, this statement needs modification to some extent for it is obvious that all healthy eyes cannot have the same acuity of vision. As the acuity depends not only upon the quality of the dioptric apparatus but also upon that of the retina, of the optic nerve and of the brain, certainly differences must arise, hence V is not always unity in the normal eye. In youth it is frequently better than unity; $V = \frac{9}{6}$ to $\frac{12}{6}$ is not uncommon and a case has been reported in which $V = \frac{42}{6.5}$ or six and a half times the normal. The writer has seen a case of a man forty-two years of age, slightly presbyopic and possessing a distance error of not over a quarter of a diopter of hyperopia read the 13-foot letters with comparative ease at 40 feet, thus exhibiting $V = 3$.

279. Visual acuity gradually declines with increasing years. Donders and de Haan assert that from the thirtieth year on visual acuity sinks one-tenth for every ten years and that between the fiftieth and sixtieth years as much as two-tenths till in the eightieth year it may be only one-half normal. This *"de Haan law"* has not, however, stood the test of further investigation. H. Cohn examined one hundred persons more than sixty years of age and found that the decrease in visual acuity was extremely slight. Boerne and Walther examined over four hundred persons and found that in the healthy eye there was a slight and uniform decrease in acuity from the fortieth year on, but that the acuity in the eightieth year period was of the order of $\frac{6}{9}$.

It is also a well known fact that some letters are much more easily read than others on the same test line. The readability of a letter is, indeed, a very complex affair and does not appear to depend altogether on the size of the intervals separating the different lines of the letters. Various attempts have been made to remedy this by constructing the test-letters less readily seen on a slightly larger scale. Likewise, the manner and degree of illumination of a chart are questions of importance; at the present time various cabinet devices, with electric lamp and metallic reflectors within, ensure a fairly uniform and sufficiently high illumination. And, again, the background and surroundings of the black test letters should be as perfectly white as possible; the writer is convinced from his experiments along this line that the readability and hence the visual acuity is considerably affected

by a cabinet frame of black as compared with one of white set upon a white wall. There has been recently pointed out the desirability of having a single small light source in a large uniform background in muscle testing; it seems, therefore, desirable that there should be some device invented whereby all these various tests may be made with the objects under inspection, and which serve as the basis of various tests, *rid of irradiation, color effects or presence of other objects in the field of view.*

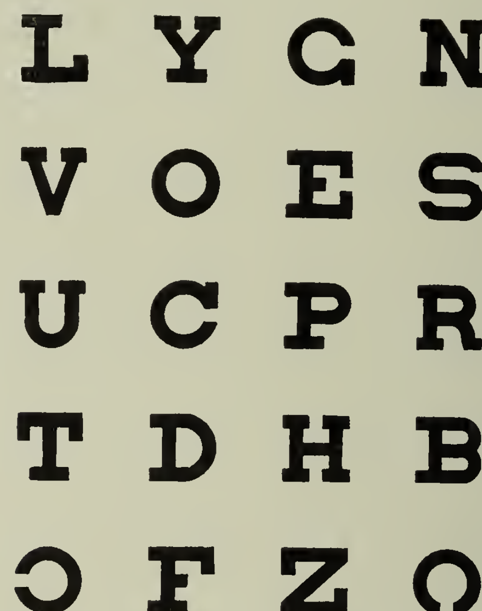


Fig. 147 (A).—Letters Subtending the Same Visual Angle: the Average Visual Acuity Required for the Recognition of Each of These Letters Varies from 0.71 for L to 1.00 for B. (From Report of Committee on Standardizing Test Cards for Visual Acuity, by E. Jackson, 1916.)

In the second Report of the Committee on Standardizing Test Cards for Visual Acuity of the section on Ophthalmology of the American Medical Association, of which committee Dr. Edward Jackson was chairman, we are told that three members of the committee made comparative tests on different individuals, noting the distance at which each letter was visible in the same light: the other two members compared the visibility of the letters at a fixed distance. The results of all tests and methods showed that B was the hardest letter to see and L the easiest. The letter B has been known for some time to be the letter which most nearly conforms to the standard five minute angle require-

ment of the Snellen test. Taking, then, the ability to recognize B at the five minute angle as standard vision, or $V = 1$, and comparing other letters with B, the average visual acuity required for the recognition of each is as follows:

L	0.71	D	0.82
T	0.74	Z	0.84
V	0.78	N	0.85
U	0.79	E	0.85
C	0.79	R	0.88
O	0.80	S	0.89
Y	0.80	G	0.92
F	0.81	H	0.92
P	0.81	B	1.00

The foregoing list necessarily gives only the order of the various letters as the averages of the different persons tested. It is perfectly obvious that two persons with full visual acuity and fully corrected ametropia will differ in the order of the visibility of these letters. "Apparently there is an individual difference in distribution of retinal elements, or in the connections and sensibilities of cerebral elements which prevents rigid exactness in the measurement of form vision." This is, therefore, an important reason for putting on test cards a fairly wide variety of letter forms.

"The positive suggestions for the use of these letters on test cards," says the Report of the Committee of 1916, "are as follows: The eighteen letters may be divided into four groups:

L T V U C
O Y F P D
Z N E R
S G H B

"Each group successively contains letters more difficult to recognize. Each line of the test card should contain at least one letter from each group; and the lines of smaller letters (the more used and more important lines of the card) should contain two letters from each group."

"The most readily visible letters have a visual acuity value of about three-fourths as great as that of the letters most difficult to see. If the interval between successive lines be not greater than this a continuous series is obtained, the easiest letter on one line being an appropriate test, when the hardest letter on the line preceding it has been recognized. When, however, the interval between successive lines represents a change of 20 per cent. in the visual acuity, the letters may be so

chosen that reading half of an additional line will indicate a gain of one-tenth in vision, and the reading of the whole line two-tenths. A sample of a test card arranged to embody these suggestions is as follows:

Five Minute Distance, Meters	Letters Used	Vision if Half are Read	Vision if All are Read
50	B	...	0.1
25	U H	...	0.2
16.67	T Z S	...	0.3
12.5	L Y N B	...	0.4
10	V D Z R G	...	0.5
8.33	C F N E S H	...	0.6
6.25	T U Y O R Z G S	0.7	0.8
5	V C D F E N S B	0.9	1
4.17	L U O Y Z E S G	1.1	1.2
3.57	U T D P Z R B H	1.3	1.4
3.12	T L Y P N E H S	1.5	1.6

280. The only test objects whose dimensions can be exactly stated in terms of a visual angle are dots and gaps, for under constant conditions of contrast and illumination the visibility of a round dot depends solely upon the size of the visual angle it subtends. The dots are arranged in groups and the person under test is required to tell the number of dots in each group. Fridenburg has used these in what he calls a *stigmometric card test;* the dots are arranged in groups and the visual acuity is shown by the ability to count the numbers in the group. In the distance tests, instead of dots, squares are used, each square and the intermediate spaces corresponding to the Snellen "*minimum separabile*" of one minute. L. Wolffberg points out that in using a dot as a test object one complies with the principle that visual acuity is to be tested by the determination of the power of perceiving an interruption of continuity; for a dot is nothing but an interruption in the continuity of the surface upon which it is printed. Wolffberg constructed a table on which the test-object is a cross consisting of four black squares arranged upon a white square of equal size. In one of the black squares a white dot is placed whose diameter is one-third that of the square. Guillery, in 1891, proposed to measure the visual acuity by the distance at which one can distinguish a black point on a white background. By comparison with the Snellen chart this experimenter found that a black dot seen under an angle of 50 seconds corresponded to the normal acuity and that at five meters it should have a diameter of 1.2 mms. This point was designated as

No. 1; No. 2 had a surface twice as large as No. 1 and the patient who saw No. 2 only at 5 meters distance had an acuity of one-half. Javal constructed a small portable scale on the same principle; it is composed of small black squares such that the side of a square is always equal to the diagonal of the preceding one; in this way the area of a square is always double that of the preceding square.

281. A method for the expression of the degrees of acuteness of vision which can be used in all languages and which aims to give an official international standard of acuity was adopted by the International Ophthalmological Congress of 1909. The test type thus officially adopted is the invention of E. Landolt and is known as the *split ring test* (Fig. 148). The following are the six general principles laid down by the Congress of 1909 relative to the principles underlying the expression of the visual acuity:—(1) the test is based upon

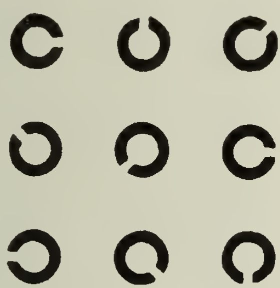


Fig. 148.—Landolt's Broken Ring Test.

the "minimum separabile" or the capacity to perceive an interruption; (2) the test is to be made by means of a black ring on a white ground, the ring to be broken at one place for a space equal to the width of the limb of the ring, which is one-fifth of its diameter; (3) the visual acuteness is to be expressed in relation to the smallest angle under which this can be deciphered, that is, to the maximum distance at which this can be done; (4) the visual angle of one minute is to be the standard of comparison; (5) the mode of expression is to be either in decimals or as a fraction ($V = \frac{d}{D}$), and (6) the eye is to be tested only at a distance from the test object.

Many believe that the charts in common use in consulting-room practice are admirably adapted to the subjective determinations of errors of refraction but that, as a test for visual acuity, they give the poorest and most inexact standards.

282. Various forms of type or arbitrary symbols all suffer from several defects; chief amongst these are that the transition from one size to another is not gradual and that the element of recognition enters in to assist the eye with certain details and not with others of the same size. Such defects are not overcome by variations of illumination or changes in the distance of the object. The ideal test object is, then, presumably one in which the size of the detail is the only variable. H. E. Ives has devised a simple apparatus in which he claims that this ideal is obtained. "It consists of a pair of oblique line gratings on glass with the lines so close as to be indistinguishable.

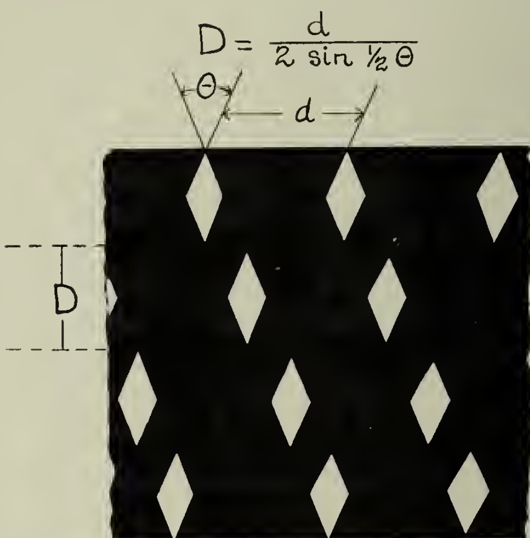


Fig. 149.—Illustrative of the Principles Involved in the Crossed Test Gratings of Ives.

These are superposed and rotated about an axis perpendicular to their surfaces. The result is the production of dark bands on a gray field. The separation of these bands is altered continuously by the rotation of the gratings. The dark bands occur where the opaque portion of the superposed gratings is continuous from side to side, the gray portions where the compound grating is alternately clear and opaque." As a result of the crossing of the lines, a set of parallel black bands appears in a direction perpendicular to the bisector of the acute angle formed and of variable width, separated by comparatively clear spaces. Mathematically it can be shown that the visual acuity varies in any case directly as the angle made by the two gratings when the resultant bands are just at the point of visibility. Fig. 149(A) shows

photographs of the gratings. The upper set are microphotographs (reproduced) of the cross-gratings set at three different angles; the lower set are photographs showing the corresponding appearance of the gratings when held at a sufficient distance.

283. *Retinal topography of the visual acuity.* A study of the visual acuity as a function of the distance of the fixation point shows a very rapid diminution. The earliest experiments along this line were carried out by Volkmann and E. H. Weber. They employed the instantaneous flashes due to the discharges of a condenser in order to

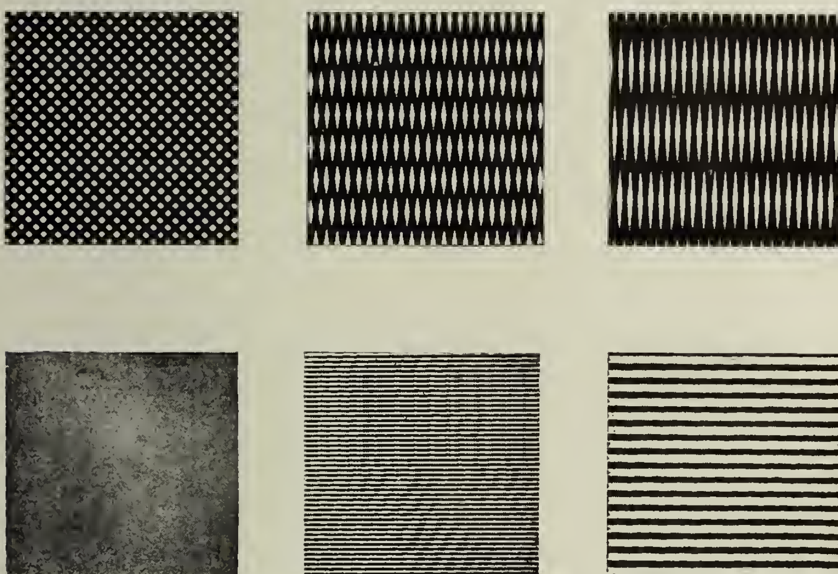


Fig. 149 (A).—Test Gratings Superposed at Various Angles. (After H. E. Ives.)

avoid involuntary movements of the eye which vitiate the results. Volkmann found the dimensions of the disassociable retinal image at various angles, measured from the fovea, given in the following table:—

0°	0.003 mm.	40°	0.193 mm.
10°	0.014	50°	0.301
20°	0.033	60°	0.442
30°	0.117		

Aubert and Foerster attempted to accurately determine the visual acuity of the various retinal zones by using different sized letters and figures from the Snellen charts which were momentarily illuminated

by an electric discharge. In another set of experiments they employed a perimeter to the carrier or cursor of which they attached a card bearing two black squares separated by an interval of white. They then determined the angular distance at which these squares ceased to be distinctly separated. The position of the arc of the perimeter gave the azimuth in which they were operating. The results obtained by

Fig. 150.—Test Object Used by Landolt and Ito.

these investigators for the horizontal meridian of the visual field are briefly tabulated below.

Angle from the Retinal Center	*Corresponding Visual Acuity*
0	1/1
2° 52′	1/5
3° 13′	1/6
3° 51′	1/7
4° 17′	1/8
7° 14′	1/12
8° 32′	1/16
10° 13′	1/19
14° 37′	1/24
16° 17′	1/45
30° 20′	1/100

Landolt and Ito extended the investigations of Aubert, making use of four sets of squares represented in Fig. 150. The results of their observations are given below, the object number I, II and so forth referring to the set of squares used while the azimuths 0, 1, 2, 3, 4—7 indicate positions of the perimeter are 45° apart starting in the vertical position.

		Azimuths							
Object		0	1	2	3	4	5	6	7
I	Landolt	12° 30′	11°	12° 30′	12°	18° 30′	16°	10° 30′	12°
	Ito	9° 30′	10°	11° 30′	10°	12°	13° 30′	10°	10°
II	Landolt	14°	13°	17°	16° 30′	22°	21°	13°	16°
	Ito	11°	12°	18°	12°	19°	17°	13°	13°
III	Landolt	21°	19°	23° 30′	22° 30′	24°	25°	21° 30′	20°
	Ito	16°	15° 30′	20°	20°	20°	22°	17° 30′	18°
IV	Landolt	25°	22°	30° 30′	28°	28°	30°	25°	26°
	Ito	20°	20°	27° 30′	25°	26°	27°	20° 30′	21°

Having given the dimensions of the perimeter it can be readily calculated that the visual acuity for the distinction of object I $= \frac{1}{14}$, object II $= \frac{1}{22}$, object III $= \frac{1}{35}$ and object IV $= \frac{1}{48}$.

284. Aubert and Foerster have given a graphical representation of the extent of the visual field in which they observed as separate two black dots of 2.5 millimeters diameter placed upon a white background at a distance of 14.5 millimeters the one from the other, the carrier being situated some 20 centimeters from the eye. Fig. 151 gives the

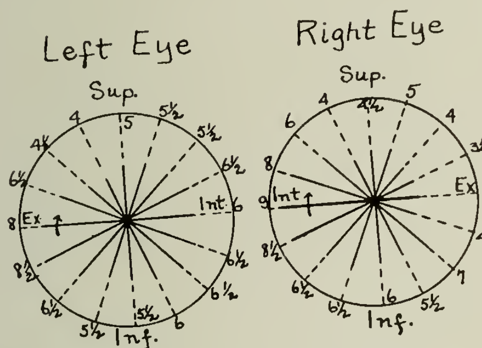


Fig. 151.—Curves Representing Extent of Visual Fields. (After Foerster.)

results obtained by Foerster; the numbers attached at the circumferences of the circles represent the distances in centimeters from the center of the visual field at which the two spots commence to be separated. It will be seen that the field for each acuity does not resemble a circle but rather an ellipse with its longer axis horizontal.

285. Fick and Koester determined the topography of the visual acuity due to the cones and that due to the rods. The acuity of the cones is the ability to distinguish forms when these are illuminated; the visual acuity of the rods is the ability which an eye, adapted to darkness, possesses of distinguishing the approximate form of objects very feebly illuminated. This latter property of the eye is a function of the visual purple and of the rods. Fig. 152 gives a survey of the retinal activities, the dotted lines representing the visual acuity due to the cones and the heavy line the visual acuity due to the rods.

286. Various hypotheses have been advanced to account for the variations of the visual acuity with the distance from the point of fixation. The cause may be attributed to a diminution in the clearness or sharpness of the image. But observations made upon beef eyes have shown that the images received upon the retina are perfectly sharp up to 70°—75° from the optic axis. These images are correspondingly smaller, it is true, at the periphery but this diminution is insufficient to explain the wide range of acuity values. One naturally turns, then, to the retina as the seat of these variations and it

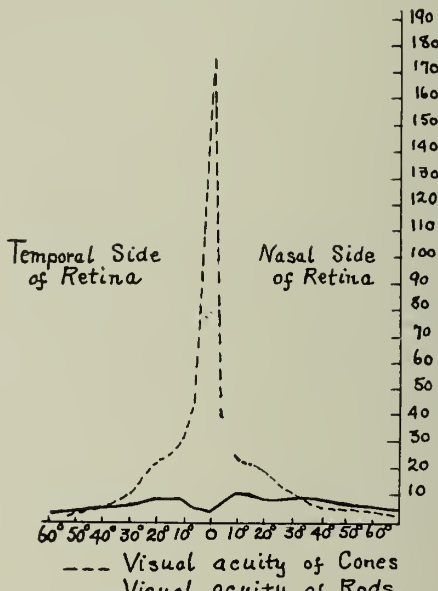


Fig. 152.—Curve (— — —) Shows Plot of Visual Acuity Due to Cones and Curve (———) Shows that Due to Rods.

is probable that the explanation is to be found here since the cones, as found in the macula, are replaced in the periphery by rods producing a sparse distribution of cones amongst the rods. It is doubtless a question of the nerve connections in the retina: the researches of Ramon y Cajal have shown that these nerve connections play an important but variable rôle. It is known, for example, that in certain cases of strabismus a new fovea or new center of fixation can be developed and that the visual acuity at this point can be augmented by exercise.

287. *The field of vision.* The field of vision of an eye is that portion of space from which an eye at rest can receive impressions of

light. A diagram of this portion of space may be projected upon any desired spherical surface described about the nodal point of the eye. The extent of the visual field is modified by the anatomical and optical structure of the bulb and by the surroundings of the eye itself. Investigation has shown that with a wide pupil the field of vision is somewhat larger than with a narrow pupil, other conditions being equal. Likewise, the field of vision becomes larger when the surface of the iris advances during accommodation for a near object; this advancement of the iris is, however, connected with the contraction of the pupil which reduces the field of vision. The extent of the retina must also be considered; in myopia of high degree, for instance, the rays entering very obliquely reach the fundus but are not perceived. In such a case as this the border of the field of vision would not be defined by the obliquity of the ray as it enters the eye but would be limited by the distance the retina extends toward the front of the bulb. Furthermore, it must be remembered that the fovea centralis does not lie exactly at the center of the retina but somewhat to the temporal side of it. The nasal side of the retina is larger than the temporal side when reckoned from the fovea centralis, hence the field of vision from the point of fixation extends farther toward the temporal side than it does toward the nasal side for, according to the laws of projection, the temporal side of the field of vision is referred to the nasal side of the retina.

288. The surroundings of an eye will affect the form of the visual field. A prominent nose or a protruding arch of the temporal bone will modify the field; deep-set eyes will be affected by the maxillary part of the socket. A droop of the upper lid will effect a noticeable reduction in the extent of the upper visual field.

289. The limits of the visual field can be determined with a perimeter or campimeter. The person under examination fixes the center of the arc of the perimeter or the center of the plane of the campimeter. The operator then proceeds to find the limiting position at which an object can be seen in indirect vision in various meridians. The object employed is usually a white square (or a colored one when the color fields are under investigation), the side of which is about one centimeter. The absolute limits of the field are found using a white object; using larger or brighter white objects does not give in general more extended limits. The reverse is true in the examinations with colors; by taking sufficiently large and bright objects one obtains larger limits than by ordinary examination. White, blue, red and green are usually employed in obtaining the fields of vision and it is found, as a rule, that the field is less extensive in the reverse order to

that in which the colors have just been named. The normal limits of the field are commonly given as tabulated below:—

	Outside	Inside	Below	Above
White	90°	60°	65°	55°
Blue	80°	50°	48°	45°
Red	65°	30°	32°	38°
Green	50°	25°	20°	28°

Deviations from these generally accepted normal limits are valuable factors in the diagnosis of and prognosis in various pathological conditions.

290. Bjerrum modified the ordinary procedure in perimetric examinations and made all tests at two meters, placing the subject in front of a black curtain and using small ivory discs of different but decreasing sizes fixed on black rods a meter in length. In this manner Bjerrum found as the limits of the normal field the following values:—

	Outside	Inside	Below	Above
With a disc of 3 mms...	35°	30°	30°	25°
With a disc of 6 mms...	50°	40°	40°	35°
Normal limits	90°	60°	70°	60°

It is said that Bjerrum's method reveals considerable contractions in cases of atrophy of the optic nerve, whereas the field as examined by the ordinary methods may appear normal.

291. There is only one interruption in the normal field and that is the blind spot which corresponds to the papilla. The form of the Mariotte's blind spot can be determined by the ordinary methods with the perimeter; the spot has an elliptical form. The internal border of this spot is about 12 degrees from the point of fixation and its diameter corresponds to about 6 degrees.

292. *Plotting the disc and macula.* It is of interest to actually locate by projection the position of the observer's disc relative to the macula and the posterior pole. The following description of the method of accomplishing this is copied from Laurance's *Visual Optics* (edition 1912).

"To do this place the eye, say the left, a certain fixed distance, e. g., 10 inches, above a sheet of paper, the other eye being closed or occluded. On the paper, mark a dot M and through M draw a horizontal straight line 'as in Fig. 153'; now take a pencil and, carefully fixing its point, cause the eye to travel slowly inwards away from M by moving the pencil to the right along the line. At a certain point A, M will disappear, showing that its image has reached the nasal side of the disc, where the sensitivity is nil. Continue the movement

of the pencil until the dot M reappears, when the pencil has reached the spot B. AB is then the lateral (projected) diameter of the disc, on a horizontal drawn through the macula. In the same way, by moving the pencil upwards and downwards on a line bisecting AB, the upper and lower extremities C and D of the disc will be located, and a rough ellipse described through the four points will represent the approximate shape of the blind spot.

"From actual measurements it is easy to calculate the distances between the macula, posterior pole P, and the disc for any given eye. For example, we know that the distance MP between the macula and the pole represents 1.25 mm. if we assume that MP subtends an angle of 5° at the nodal point, i. e., that the angle alpha is 5°. Further, by measuring PA, it is a matter of simple proportion to find the length

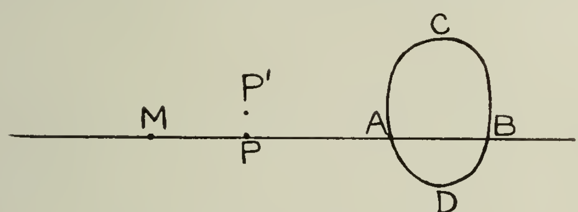


Fig. 153.—Plotting the Blind Spot.

of the eye to which PA corresponds. Thus, supposing the experiment were made at 10 inches or 250 mms. we have—

$$d : PA :: 15 : 250$$

where d is the actual distance from pole to disc required, and 15 the distance in mms. of the nodal point to the retina, whence

$$d = \frac{PA \times 15}{250}$$

"If PA be 40 mms., d is then 2.5 mms., which is about the value found in practice. It will be noticed that the horizontal line passing through M cuts the disc near the lower edge, proving that the macula is below the center of the disc; thus the maximum width of the latter is not represented by AB. Assuming the disc to be level with the posterior pole, the true position of P will be in the neighborhood of P^1, although for practical purposes we assume that the macula, posterior pole and center of disc, are all on the same horizontal line. The method of sketching indicated is easy and convenient, in that it gives an *upright* representation instead of an inverted one; the latter is obtained by fixing the point M and moving the pencil about to locate, as in the perimeter, the confines of the disc. This, however, is not so

accurate unless a small object, such as the head of a large pin, be substituted for the pencil."

Factors Affecting the Visual Acuity

293. I. *Influence of age and of sex upon the visual acuity.* De Haan determined the average acuities for each decade as follows:—

Age	*Visual Acuity*
10	1.18
20	1.15
30	1.1
40	1.03
50	0.94
60	0.83
70	0.70
80	0.55

These results have been criticized and it is claimed by several investigators that the acuities as given by de Haan in old age periods are

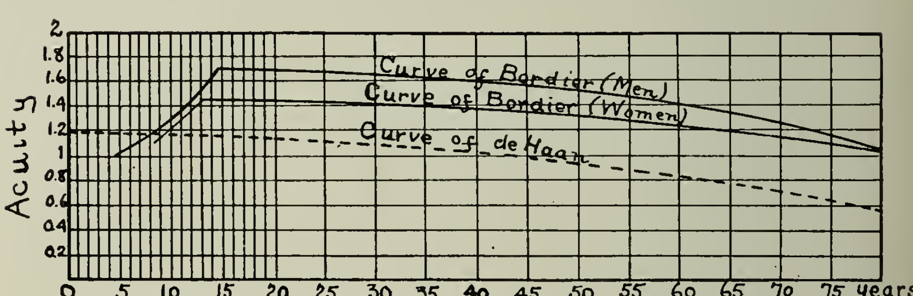


Fig. 154.—Curves of the Variation of the Visual Acuity with Age. (After Bordier.)

too low. Bordier has carried out extended researches on this question and has given his results on the effects of age and sex upon the acuity in the accompanying diagram (Fig. 154); de Haan's results are shown by the dotted line. These investigations show that, on the average, the normal acuities are higher for men than for women and that the maximum point is reached at an earlier age in life for females than for males; the visual acuities for the two sexes approach equality at about the 80-year point showing an acuity about equal to unity. It is a fact well known to all practitioners upon the eye that young emmetropes and hyperopes of low degree invariably possess,

according to the commonly used Snellen charts, an acuity in excess of unity, ranging from $V = {}^{20}\!/_{16}$ to $V = {}^{20}\!/_{10}$.

294. II. *Influence of the retinal adaptation upon the visual acuity.* De Haan and Pickema found that there were noticeable differences in the visual acuities of their eyes under the same lighting conditions which apparently depended upon variations in the retinal adaptation. Broca has since investigated this phenomenon in some detail. He used an apparatus carrying either a black screen, in order that darkness adaptation conditions might be produced, or a white screen, suitably illuminated by an auxiliary light source the distance of which from the screen could be varied, which served as an adaptation center. The brightness of this source was then compared with that of the aerial image of a test object of known brightness. An artificial pupil of 2 to 2.5 mms. was employed to eliminate the influence of the pupillary diameter and thus obtain the true effects of retinal adaptation upon the form sense. Broca's results indicate:—(1) for low intensities of illumination the visual acuity increases with darkness adaptation, (2) for average luminosities the visual acuity remains the same whether the retina is adapted or non-adapted, (3) for high intensities of illumination the visual acuity decreases with darkness adaptation. The accompanying table gives a digest of some of the experimental evidence as to the relations between adaptation conditions, luminous intensities and visual acuities.

Brightness (Lux)	*Visual Acuity* Eye Exposed to Light	Eye Adapted to Darkness
2	0.52	0.81
17	0.86	0.97
34	1.00	1.00
170	1.55	1.15

295. III. *Influence of the pupillary diameter upon the visual acuity.* The variations of the size of the iritic diaphragm exercise two effects, which are opposed one to the other, upon the visual acuity. The pupillary dilatation increases the visual acuity in that it re-inforces the luminous intensity of the retinal images; but, by virtue of its participation in the formation of these images in the eccentric portions of the retina, it diminishes their sharpness and therefore reduces the acuity. Hence the pupillary contraction which is favorable to the sharpening of the retinal images diminishes the luminous intensity; it follows, therefore, that the pupillary contraction will increase the visual acuity if the surrounding luminosity does not fall below a

definite amount. Likewise, if an ametropic eye is not corrected, the influence of the pupillary diameter is considerable, for the diameter of the diffusion circles is proportional to the diameter of the pupil. The chief difficulty in determining the influence which the size of the pupil of an emmetropic eye has upon the visual acuity lies in the exact experimental determination of the apparent size of the pupillary diameter, for if this can be found the real dimensions thereof can be obtained by calculation. Bordier, by a series of ingenious experiments, determined the apparent pupillary diameter by the aid of instantaneous photography; the visual acuity was monocularly determined for a given value of the size of the pupil. Various devices were employed to obtain large pupils; darkened rooms with charts illuminated by light reflected from external sources carefully screened from the observer were used. The results of Bordier's experiments are given below:

Apparent Diameter of the Pupil	*Real Diameter of the Pupil*	*Corresponding Visual Acuity*
2.06 mms. (daylight)	1.8 mms.	2
4.48 mms. (average illumination).	3.9	1.85
4.65	4.04	1.8
6.9	6	1.75
9.58	6.8	1.70

It is obvious, therefore, why objects which are seen dimly become more distinct when viewed through a stenopaic disc, since the aperture, being smaller than the pupil, diminishes the circles of diffusion. This is the reason why myopes see better at a distance through a small opening. Such an opening can be, as a matter of fact, used as a magnifying glass; the object which is to be examined can be moved close to the eye and large retinal images thus obtained. The more the diameter of the aperture is diminished the sharper the image becomes but it loses at the same time in brightness; a certain limit cannot, however, be exceeded as the distinctness of the image becomes blurred by diffraction effects.

296. Percy W. Cobb has recently published (*American Journal of Physiology*, 1915) the results of some investigations upon the influence of pupillary diameter on visual acuity. One of the functions of the pupil is that of compensating for the defects of the refracting system of the eye. By a reduction of the size of the light-pencil the area of the diffusion circle is decreased and the image is sharpened, the effects of chromatic and spherical aberration and regular or irregular astig-

matism being partially eliminated or diminished. It is, however, a well known fact of physical optics that, owing to diffraction at the margins, the aperture of an optical system places a limit upon the resolving power of a system according to the expression

$$\theta = 1.22 \frac{\lambda}{D}$$

where θ is the angular separation in radians of two just resolvable bright points, λ the wave-length of the light considered and D the diameter of the circular aperture. The constant 1.22 is empirically determined. Hence, increasing the diameter of the pupil should bring greater clearness of image. Cobb's investigations attempted to weigh the relative importance of these two factors as they apply to the human eye.

The test-object was the Ives' cross-grating standard (previously described) which was so arranged that while observing it the observer could change the width of the lines seen upon its face and while he was so doing, keeping the lines always as near as possible at the point of just-visibility, the movements of the test-object were recorded on the drum of a kymograph. Artificial pupils of various sizes were used and placed close to the observer's eye. Since the visual acuity is a function of the illumination upon the retina, other factors remaining constant, and the object of these experiments was to investigate the clearness of optical images, the retinal illumination had to be equalized by varying the brightness of the test-objects inversely as the area of the artificial pupil and thus making the flux upon the eye constant. From his experiments Cobb concludes: (1) By the use of circular diaphragms before the eye it is shown that an aperture for optimal visual acuity exists somewhere between the limits of 1 and 5.6 mms. for brightness of test-object between 5.9 and 189 candles per square meter. (2) When the illumination of the test-object is compensated for the size of aperture to give equally illuminated images upon the retina, the optimum is somewhat less than when the test-object is constant and the illumination of the image depends on the pupillary area. In the former case it falls on the average at 2 to 4 mm., in the latter at 4 mms. Similar differences are shown in the case of each of the observers, but those having on the whole the highest visual acuity show also a larger optimum pupil. (3) With an aperture of 1 mm. diameter the observers give almost identical results, which agree closely with calculated results. (4) The optimum pupil corresponds on the whole with the size of pupil accepted as normal for all except extreme conditions: 2.8 to 4 mms. From this lower limit up to 5.6 mms. the

variations in visual acuity with size of aperture are not large enough to be of practical importance. (5) The tabulated experimental results obtained from Cobb's curves show the following:—

Brightness Compensated		Constant Brightness of 189 candles per square meter		Constant Brightness of 5.92 candles per square meter	
Diameter of Artificial Pupil	Relative Visual Acuity	Diameter of Artificial Pupil	Relative Visual Acuity	Diameter of Artificial Pupil	Relative Visual Acuity
1	4	1	4	1	3.5
1.4	5.3	1.4	5	1.4	4.45
2.0	6.7	2.0	6.05	2.0	5.25
2.75	7.1	2.75	6.05	2.75	6.00
4	7.2	4	6.10	4	6.15
5	7.0	5	5.8	5	5.80
5.60	6.8	5.6	5.75	5.6	5.70

297. Broca has recently given the results of some investigations on the contraction of the pupil and the resulting loss of illumination caused by placing various sources in the direct range of vision. The well known effect of lamps placed in the field of view is to cause the pupil aperture to contract with the result that the luminosity of other moderately bright surfaces is enormously reduced and they appear very dark in comparison with the source from which their brightness is derived; indeed, for this reason, a bright lamp placed between the observer's eye and the object illuminated may even render it impossible to distinguish the latter at all. The following, for example, represent the contraction of the pupil and the resulting loss of illumination when various light sources are put in the direct range of vision.

Lamp	Pupillary Diameter	Fraction of Light Used
No source in field of view............	12 mms.	1
Incandescent lamp	8	0.43
Mercury lamp	6.8	0.32
Arc lamp in globe...................	6.7	0.25 — 0.34
Naked arc lamp.....................	5.7	0.22

It will be seen, therefore, that the apparent gain in illumination following the use of a high illuminant is soon lost owing to the fact that it causes a marked contraction of the pupil; hence the use of bright sources in the direct line of sight is not only of marked inconvenience to eyesight but is not even economical.

298. IV. *Influence of the luminous intensity upon the visual acuity.* In general the visual acuity increases when the illumination is in-

creased and diminishes when its intensity is decreased. In investigating the visual acuities which correspond to different luminous intensities it is indispensable to obtain a "dark adapted" retinal condition. The visual acuity depends directly upon the illumination of the chart, but it is difficult to determine the relation in a precise manner since there are many factors which may affect it. The influence of the adaptation of the eye has been mentioned; the pupillary size, the manner of contraction of the pupil and degree of optic perfection all exert an influence. Aubert, in 1865, determined the surface of the aperture in the window of a blackened cabinet which would permit of the reading of the different lines of Jaeger type at a distance of one meter; from his results he was able to calculate the relation between the luminous intensity (I) and the visual acuity (V). Carp used smoke glass of various depths of shade of known absorption power. He found that ordinary daylight can be reduced to 0.05 of its normal amount without causing a diminution in the visual acuity of emmetropes; in the case of myopes and of the aged the visual acuity diminishes more rapidly, for a reduction to 0.12 of diffuse daylight produced a diminution in the acuity. Druault utilized artificial illumination in his measurements; his method consisted in moving a candle toward the test-chart and noting the distances at which the light would allow each line to be read, the eye being in a state of medium adaptation. For higher degrees of illumination he replaced the candles by a lamp equivalent to 54 candle power. The unit of illumination was taken as one candle at the distance of one meter, or the so-called "meter-candle." The experimental results of Carp, Druault and Uhthoff are as follows:—

Carp		*Uhthoff*		*Druault*	
I	V	I(m.c.)	V	I(m.c.)	V
0.12	1	0.0015	0.0015	0.016	0.075
0.07	0.96	0.0014	0.004	0.020	0.15
0.05	0.87	0.01	0.043	0.028	0.21
0.04	0.74	0.1	0.07	0.047	0.30
0.02	0.61	0.6	0.21	0.12	0.37
0.008	0.51	1.5	0.34	0.25	0.50
0.004	0.35	6	0.74	0.67	0.75
0.003	0.23	15	0.93	1.50	1.00
		36	1.14	16.7	1.25
		144	1.59	540	1.50
		1175	2.0		

All methods of observation show conclusively that the visual acuity increases at first quite rapidly with small changes in the illumination but that finally a very large increase in luminosity is demanded in order to change the acuity by a small percentage.

299. Piekema and Laan, two pupils of Snellen, investigated the influence of illumination upon the acuity by taking every possible precaution to exclude perturbing influences due to retinal adaptation. They reduced their observations to curves in which the abscissæ represent the acuities and the ordinates the luminous intensities expressed in meter-candles. These curves are reproduced in Fig. 155. It will be observed that the visual acuity of one experimenter was practically double that of his collaborator, yet both curves show the same general

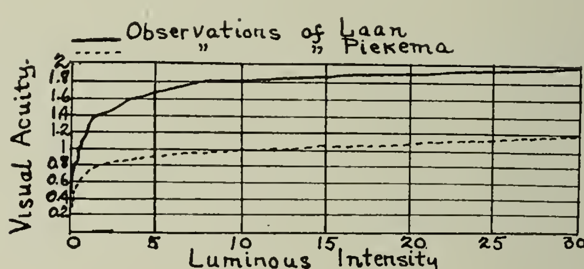


Fig. 155.—Variations of the Visual Acuity Dependent upon Variations of the Luminous Intensity.

effects of the intensity of illumination upon the visual acuity. Experiments made to demonstrate the effects of retinal adaptation show that such curves as those presented in Fig. 155 are modified in a manner which indicates that the increments in the acuity corresponding to small changes in the illumination are very much less for the non-adapted retina.

300. These relations between acuity and illumination for a single eye are altered somewhat when binocular vision is enjoyed. Nicati and Macé de Lépinay, and Snellen, have investigated this question as well as the influence of diaphragms upon monocular and binocular vision. The gist of their results is shown in the curves of Fig. 156 in which curve *A* shows the average results obtained binocularly without diaphragms, curve *B* monocularly without a diaphragm, curve *C* binocularly through diaphragms of 2.75 mms. diameter and curve *D*

monocularly with the same sized diaphragm. These curves show that the acuity-luminosity curves for binocular vision are of the same shape as those obtained for one eye only but give, as is commonly known, higher acuities binocularly than monocularly. The influence of apertures is seen to be most marked when the intensities of illumination are feeble; this is obvious since the pupils will be large under low illuminations, while the apertures of the diaphragm will be small in comparison.

301. We may, therefore, conclude in a general way that different methods and test-objects yield different absolute results but the relation between visual acuity and brightness of the background is in general the same. It is seen that when the brightness of the background is low the visual acuity increases very rapidly with increasing

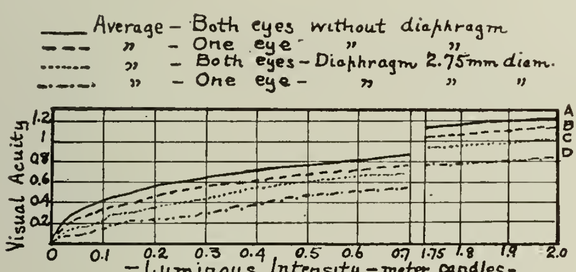


Fig. 156.—Variations of the Visual Acuity with the Luminous Intensity.

brightness of the background; after the brightness has reached a certain value, e. g., when the illumination has reached an intensity of one foot-candle, the visual acuity increases only very slowly with increasing brightness of the background. The relation for ordinary intensities may be thus expressed:

$$\text{Visual acuity} = k \log. I$$

in which k is a constant and I is the intensity of illumination. Experimentation shows that the value of k is not the same in the low and medium regions of illumination.

302. V. *Visual sensitiveness and acuity.* By the term visual efficiency is meant the ratio of the service rendered to the eye to the expenditure of nervous energy. The proper maintenance of visual efficiency demands attention to two important factors which we have discussed, viz., the sensitiveness of the eye to differences of luminosity

and the acuity of the eye. Fig. 157 indicates the variation of the sensitiveness of the eye to differences of luminosity and the variation of its acuity with the luminosity of the field when white light is used. It will be noted that the two curves become asymptotic after passing a luminosity of one lumen per square foot. This may be summarized into a working principle by which the degree of illumination required for any surface to meet the ordinary optical requirements may be ascertained, to wit:—the illumination of any surface requiring the continued application of the eyes shall be such that the light reflected or transmitted by it shall be equivalent to a luminosity of approximately one lumen per square foot. Inadequate luminosity and exces-

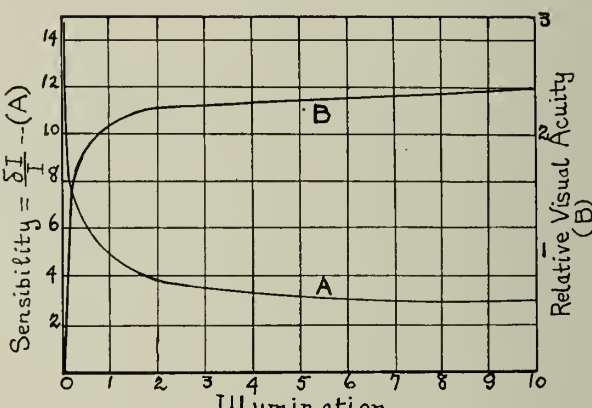


Fig. 157.—Sensitiveness and Acuity of the Eye for White Light.

sive luminosity of the direct field of view are about equally undesirable. In the former case the retinal images are not distinct and the eye grows fatigued in its efforts to sharpen their perception. Excessive brightness produces images which are intensely bright causing injury to the retina. Optical and engineering specialists differ in their estimates of the safe maximum of intrinsic brilliancy for direct vision; the values range from 1.75 to 5 candle-power per square inch of apparent light source.

303. VI. *Visual acuity in lights of different colors.* In his experiments upon the influence of the intensity of illumination upon the visual acuity Cohn made some observations using monochromatic light sources and found that the visual acuity attained a maximum value

under yellow light. Under an illumination of 36 meter-candles he obtained the following results:

Light	*Visual Acuity*
White	2
Yellow	2.15
Red	2.00
Green	0.66
Blue	0.37

Macé de Lépinay and Nicati as collaborators and Uhthoff came to the conclusion that it is possible to attain the same visual acuities with any color of illumination provided sufficiently high intensities are employed. The first two of the above named experimenters studied the visual acuities in the different colors as a function of the objective luminosity; they concluded from their curves that the acuity is the same for all radiations of wave-length greater than 5,070 Angstroms when taken in conjunction with the Purkinje phenomena. Taking as the unit for each color that luminous intensity which gives a visual acuity of 0.33 they obtained the following results:—

Visual	Intensity of Illumination				
Acuity	$\lambda = 5070$	$\lambda = 4970$	$\lambda = 4580$	$\lambda = 4420$	$\lambda = 4280$
0.47	5.00	8.18	....	....	....
0.42	2.67	3.71	5.48	6.51	....
0.33	1.00	1.00	1.00	1.00	1.00
0.26	0.48	0.38	0.22	0.21	0.18
0.22	0.33	0.23	0.13	0.12	0.10

It will be seen, therefore, that the visual acuity increases and decreases more slowly for the colors having short wave-lengths than for the less refrangible radiations for any given variation in the objective luminous intensity and that this difference is all the more accentuated when one has under consideration radiations which are more refrangible than $\lambda = 5{,}070$ Angstroms. The luminous intensity can vary considerably in the blue without appreciably influencing the visual acuity. And, again, if a test object is lighted in turn by different portions of the same spectrum it will be found that the clear recognition of the object is due solely to the illumination furnished by the less refrangible portion of the spectrum.

304. It has already been pointed out that the eye is not achromatic, with the result that the image of an object illuminated by light of

rather wide spectral limits is not sharply defined upon the retina. Bell has compared the acuity of the eye in tungsten and mercury arc lights and has obtained results indicating an advantage for this latter illuminant; this is probably to be attributed to the more nearly monochromatic character of the light from the mercury arc. Luckiesh has confirmed these results and extended them using lights of the same color but differing in spectral character; this is possible by employing proper absorbing solutions. Some of the results of Luckiesh are given in the subjoined table; it is to be remarked that "His data, except in case 4, were not obtained by the method of using fine detail at the limit of discrimination but instead in terms of equal readability of a page of type, which proved after some practice to be a rather definite criterion."

Relative Illumination for Equal Readability

Case	Source	Color	Approximate Foot-candles	Relative Illumination
1	Mercury Arc	Green line	2.0	1.00
	Tungsten	Green		1.75
2	Tungsten lamp	Yellow	4.0	1.00
	Tungsten lamp	Yellow (diff. shade)		1.33
3	Sodium line	Yellow lines	0.5	1.00
	Tungsten lamp	Yellow		1.66
4	Mercury Arc	Green line	0.5	1.00
	Tungsten lamp	Green		5.10

No stress can be laid upon the accuracy of the absolute values given above but these and similar results from other experimenters make it conclusively evident that monochromatic light is superior for discriminating fine detail. It has been found that monochromatic light is superior to daylight for such discrimination. In this case the Ives' acuity object was viewed against a white magnesium oxide surface which was illuminated to an intensity of approximately one foot-candle. The acuity on the Snellen scale was found to be 1.11 and 1.28 respectively for daylight and monochromatic green light of equal intensities; another experiment showed that for a visual acuity of 1.28 on the Snellen scale the intensity of illumination with daylight or tungsten lamps was nearly three times that required for the same visual acuity with monochromatic green light. As the brightness of the background was increased it was found that the difference in visual acuity under a given illumination of tungsten light and monochromatic light decreased. Luckiesh has recently conducted a very thorough-going series of experiments for determining the visual acuity

in monochromatic lights. His results are platted in Fig. 158. Curves *a* and *e* represent extreme series of observations made by the experimenter showing the fluctuation in the ability of the eye to distinguish fine details; curve *b* is the average of a great many observations. These investigations indicate that monochromatic lights differ in their defining power and that yellow monochromatic light is superior to others in this respect. It was also found that for any given change in brightness of the test-object the change in visual acuity was least for yellow monochromatic light.

305. *Relations between the refractive condition of an eye and its visual acuity.* The relative size of the retinal image depends upon the visual angle under which the object appears and upon the distance of the second nodal point from the retina of the eye, the size of the

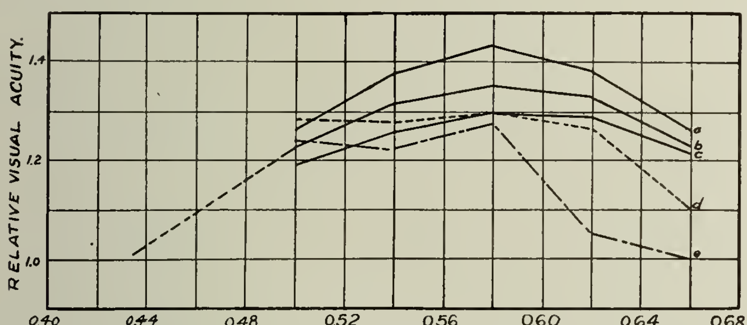


Fig. 158.—Visual Acuity in Monochromatic Light of Equal Brightness.

image being proportional to this distance. The distance of the nodal point from the retina and, therefore, the sizes of the retinal images varies due to the influence of accommodation and of the ametropia. In order to eliminate both sources of error Donders laid down as fundamental that the visual acuity be measured at a distance sufficiently large to exclude the influence of accommodation and that the ametropia be corrected. When the ametropic error is axial, the employment of correcting lenses gives to the retinal images the same relative sizes which they would have in an emmetropic eye in a state of repose on the condition that the correcting lens is in the plane of the anterior focus of the eye. In cases of ametropia due to curvature, however, the correcting lens still permits of the existence of an inequality in the size of the retinal image as compared with the emmetropic eye, but this inequality can be in general neglected under the methods in current use for determining visual acuity. In the state

of accommodation, which is a condition of temporary myopia of curvature or, in certain cases where convex spheres are employed to replace accommodative action, the two nodal points will be displaced forward towards the cornea. This displacement increases the distance of the nodal points from the retina and, therefore, the size of the retinal images. For the accommodation necessary at a quarter of a meter it can be shown that the relative increase of the retinal image is approximately one-fifth of the size which it possesses when in a state of repose.

306. In Fig. 159 are diagrammed simple axial ametropic conditions in which the angle subtended at the nodal point is the same, but the retinal images of the object AB vary in size. E_1E_2 represents the image of the object formed by the emmetropic eye, while H_1H_2 and M_1M_2 indicate these images in cases of axial hyperopia and myopia respectively. We need, then, only to imagine three eyes which are

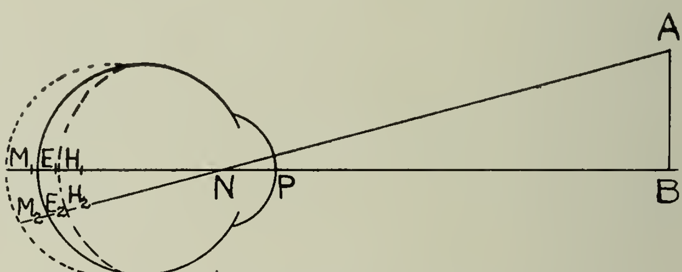


Fig. 159.—Relations Between Refraction and Visual Acuity—Axial Ametropias.

respectively emmetropic, myopic and hyperopic, the ametropia in the latter two being due to differences in axial length. With the accommodation at rest, each will form images equal in size by virtue of the equality of their dioptric powers, but the images of a distant object will not be clearly defined in the hyperopic and myopic eyes since they do not fall on the retina. The hyperope, with the aid of his accommodation, increases his refraction sufficiently to bring the image forward to the retina but at the same time he shortens his anterior focus and hence obtains a smaller image than the emmetrope. The myope is, of course, unable to obtain a sharp retinal image of a distant object. If, on the other hand, the three eyes view the same object at such a distance that all three can receive clear, sharp images upon their retinæ, i. e., let the object be at the punctum remotum of the myopic eye, then the latter, in which no accommodation is exerted, has the largest retinal image, the emmetropic image being next and that under the hyperopic conditions being the smallest.

307. In Fig. 160 we have considered curvature ametropias, which are produced by a variation in the curvature of the cornea or the crystalline lens. The object AB gives rise to the retinal images RH, RE and RM due respectively to hyperopia, emmetropia and myopia. N_2, N and N_1 represent the single reduced nodal points for hyperopic, emmetropic and myopic conditions. These three points, it will be remembered, coincide with the centers of curvature of the cornea of the reduced eye in each refractive state. The sizes of the images, therefore, increase from the hyperopic to the myopic states when due to curvature variations.

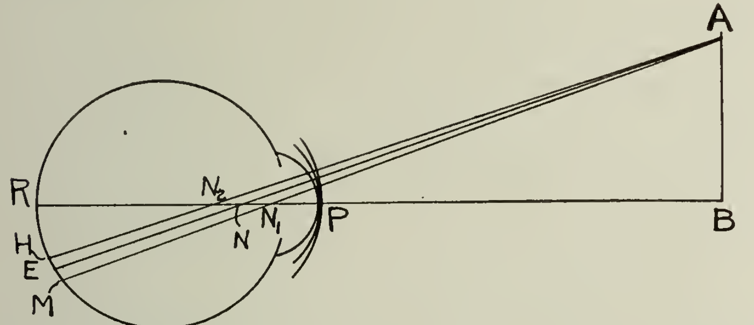


Fig. 160.—Relations Between Refraction and Visual Acuity—Curvature Ametropias.

308. If the ametropia is *refractive* due to abnormal indicial conditions, however, the axial length of the globe being the same in each case, the conditions described in connection with axial ametropia are reversed. When the accommodation is relaxed in the three conditions, the image formed in the vitreous of the myopic eye is the smallest of the three, the emmetropic being next and the hyperopic being the largest if the retina were to be conceived of as removed in order to permit of the formation of the image. Hence, with the object placed at the far-point of the myopic eye, there will be the same sized image in the hyperopic, emmetropic and myopic states since the hyperope and emmetrope, by means of accommodation, shorten the focal length of the eye sufficiently to enable the image of an object at a distance corresponding to the myopic punctum remotum to be formed on the retina.

309. It is not difficult to show that the following is correct in cases of the correction of axial ametropia, namely: *a lens placed in the anterior focal plane of the eye has no effect on the size of the image formed, the latter being merely moved forwards or backwards as the*

case may be; the image is, then, of the same size as in emmetropia. If, therefore, it were possible in cases of axial ametropia to place the correcting lens exactly at the anterior focus of each eye the retinal

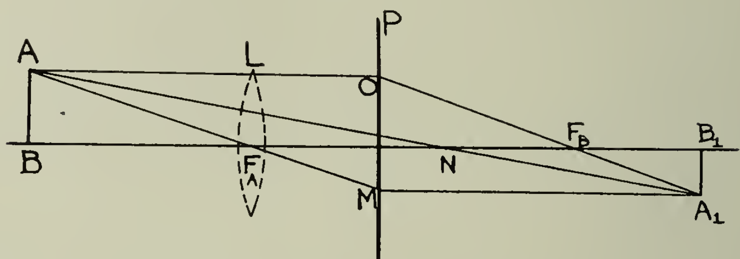


Fig. 161.—Image Formation not Changed in Size but in Position when a Lens is Inserted at the Anterior Focus of the Eye.

images would be identical in size neglecting the influence of aberration and distortion produced by the lenses. In Fig. 161, let P be the single refracting plane of the eye, N the single or united nodal point

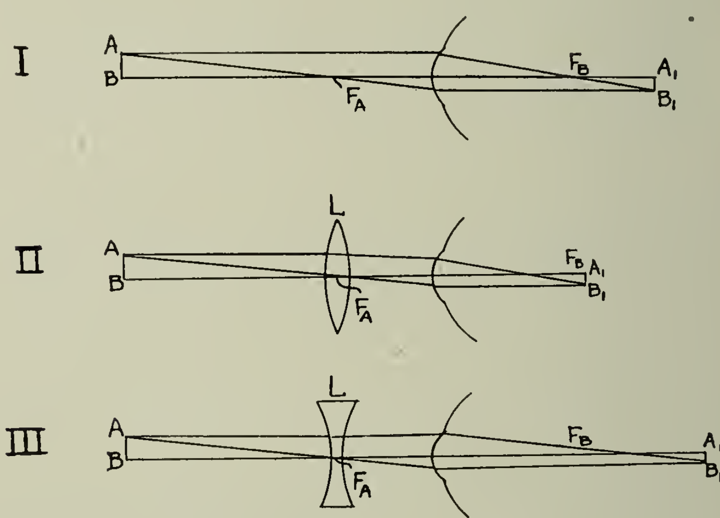


Fig. 162.—Effects of Lenses Inserted at the Anterior Focus of the Eye upon the Position of the Image.

and F_A and F_B the anterior and posterior focal points. The image of an object AB is easily constructed by tracing the courses of the three known rays AO, AN and AM. The ray, AM, passing through the anterior focus F_A, is refracted parallel to the axis BB_1; AO, parallel to the axis, passes, after refraction, through the posterior

focus F_B and AN, through the center of curvature or single nodal point, proceeds without deviation. If a thin lens of any power or sign is placed at F_A, as in Fig. 161, the image will not be altered in size since the direction of the ray AM is unaltered by the lens because it passes through the optical center of this lens and the ray BF_AN passes through without refraction. To be exact, therefore, one should say that the optical center of the lens is to lie at the anterior focus of the eye. The image A_1B_1 is merely brought forward by a convex lens or carried backward by a concave lens. The three conditions are diagrammed in Fig. 162. Diagram I represents an object AB and A_1B_1 its image without an auxiliary lens before the eye. Diagram II is the same having a convex lens in the anterior focal plane, the image A_1B_1 being drawn forward but not changed in size. In Diagram III, the effect of the concave lens is to throw the image farther back of the cornea but to leave it of the same size.

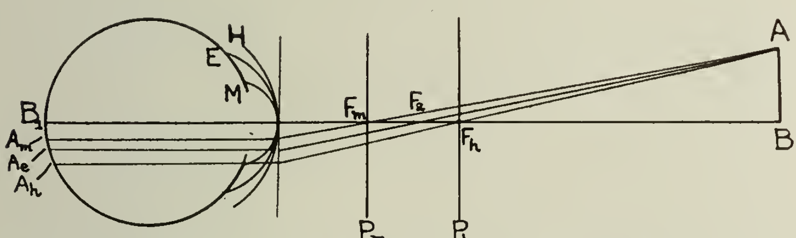


Fig. 163.—Illustrative of the Variation of the Retinal Image when the Position of the Anterior Focus Changes.

310. It is likewise easily seen from a consideration of these diagrams that the size of this image A_1B_1 will vary, however, when the position of the anterior focus F_A changes as in cases of curvature ametropia. The condition of affairs will then be somewhat as pictured in Fig. 163, in which F_e represents the anterior focus corresponding to the emmetropic refraction. The anterior focus, F_m, of the myopic eye will be nearer and the point, F_h, of the hyperopic eye will be farther from the cornea than for the emmetropic eye in *curvature* ametropias. P_h and P_m represent the correcting lenses for the curvature hyperopia and myopia placed at the respective anterior focal points of an eye possessed of these curvature variations. By construction, using the rays from A passing through these various anterior focal points, we find that the retinal image formed by the eye which is myopic due to curvature is smaller than that formed by the emmetropic eye which, in its turn, is smaller than the image formed under the curvature

hyperopia. If the lens which corrects the curvature ametropia could be placed in contact with the cornea it would then be possible to make the anterior focal distances of the myopic and hyperopic eyes equal to that of the emmetropic eye; in that case the retinal images would be of the same size in all three cases. Since the visual acuity is proportional to the size of the retinal image it follows that it will be increased by a lens correcting the hyperopia due to curvature placed at the anterior focus of the eye and diminished by a lens correcting the myopia caused by curvature when placed at the ocular anterior focus. Since the correcting lenses cannot be placed in contact with the cornea but are always placed at distances from the eye ranging from eight to fifteen millimeters, the retinal images of a series of test-objects thereby obtained do not indicate the linear distances corresponding to the visual acuity which they are presumed to measure.

311. Widmark measured the visual acuity of the myopic students in the schools of Stockholm and found that the visual acuity of corrected myopes, comprised between zero and eight diopters, showed a gradual diminution. The average values taken from his tables show the following:—

Myopia (Diopters Correction)	*Visual Acuity*
0.5	1
1.5	0.85
3.0	0.80
4.0	0.72
...	....
8.0	0.60

Seggel, after examining some sixteen hundred soldiers from twenty to twenty-five years of age, concluded that the apparent visual acuity, i. e., the acuity of the eye when wearing its correction, was less than for emmetropes. Nimier found an inferiority in the acuity of hyperopes. In cases of compound hyperopic astigmatism in which the irregularities of the cornea produce a diminution of the visual acuity it is found that the wearing of the correcting lenses gives larger retinal images than in emmetropia.

312. It is possible to distinguish between the visual acuity which the ametropic eye possesses when it re-unites upon its retina the luminous rays without the aid of correcting lenses and that acuity procured with external lens assistance. The first of these constitutes the *true* visual acuity of the ametropic eye and the second its *apparent*

visual acuity. Bordier * has defined the true visual acuity in the following manner: The true visual acuity of an ametropic eye is that which is obtained without changing the visual angle by correcting lenses. The acuity of an ametropic eye determined under the condition of constancy of angle is that which this eye possesses without the aid of correcting lenses when sharp, clear retinal images are obtained of test-objects presented in such a manner that the myopic eye receives divergent rays and the hyperopic eye convergent rays (Badal's optometer). Bordier proposed as a definition of the true visual acuity that which is obtained when the visual acuity of the corrected ametropic eye is measured by placing the test-objects in such a manner that an eye receives parallel light.

313. In Fig. 159 are shown the retinal images in emmetropic and axial ametropic conditions under the constancy of visual angle. In Fig. 164 is sketched a diagram of an emmetropic and of an hyperopic

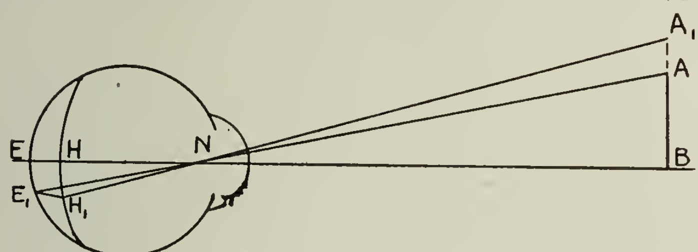


Fig. 164.—Equality of Retinal Images of the Emmetropic Eye and the Axial Hyperopic Eye Corrected: Inequality of Visual Angles.

eye in which the retinal images are made equal, the axial hyperopia being corrected by a proper convex lens placed at the anterior focus of the eye. The inequality of the visual angles in the two cases is apparent. We therefore conclude that the placing of a lens correcting an axial ametropia in the anterior focal plane of the eye produces an equality in retinal images by comparison with the emmetropic eye but that the object appears under a different visual angle from that of the emmetrope. For the hyperopic eye this angle is greater and for the myopic eye it is less than in emmetropia.

314. If, then, V represents the *true* visual acuity and V_a signifies the *apparent* visual acuity it can be shown from Fig. 164 or similar constructions that

$$V = V_a(1 \pm R \cdot f)$$

* D. E. Sulzer, writing upon the "Determination Qualitative et Quantitative des Fonctions de la Rétine" in the third volume of the *Encyclopédie française d'Ophthalmologie* says:—"Il (Bordier) propose de l'appeler acuité *vraie* de l'oeil amétrope, par opposition à l'acuité *apparente,* qu' on obtient quand on mesure l'acuité visuelle de l'oeil amétrope corrigé en disposant les optotypes (optometer of Badal — — inserted by the writer of this manual) de façon que d'oeil amétrope corrigé reçoit des rayons parallèles."

where R represents the degree of refractive error in diopters and f the length of the reduced emmetropic eye which we have taken as 20 mms. This formula shows that the true visual acuity of an axially myopic eye is greater than the apparent acuity, while in the case of hyperopia it is less. In the case of curvature ametropias the differences are in the same direction but considerably different in amount. The four formulæ can be written as:

$$(1)\quad V_a = \frac{V}{1 + 0.02R} \quad \text{for axial myopia}$$

$$(2)\quad V_a = \frac{V}{1 - 0.02R} \quad \text{for axial hyperopia}$$

$$(3)\quad V_a = \frac{V(15R + 1)}{20R + 1} \quad \text{for curvature myopia}$$

$$(4)\quad V_a = \frac{V(15R - 1)}{10R - 1} \quad \text{for curvature hyperopia}$$

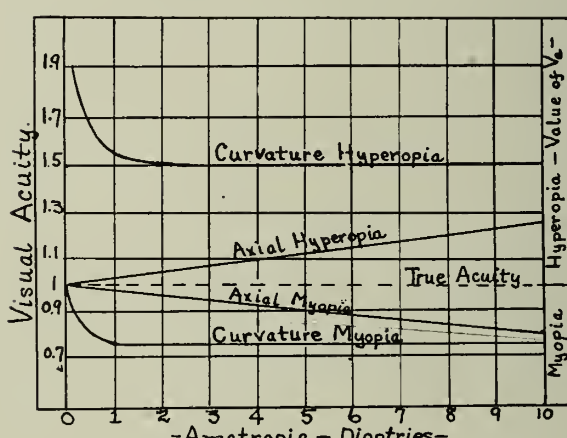


Fig. 165.—Graphic Representation of the Relations which Exist Between the True Visual Acuity and the Apparent Acuity in Different Conditions of Ametropia. (After Bordier.)

Fig. 165 gives a graphical representation of the relations which exist between the *true* and *apparent* visual acuities in different ametropic conditions from Bordier's work. These are the values of the apparent acuities, the basis of the true acuity being taken as unity.

By substituting in the above formulæ for V (the true acuity) the value of unity and in place of R (the degree of error) in turn the

values from 1 to 10 diopters, one obtains the following tabular results:—

I. Axial Myopia

Degree of Myopia (R) in Diopters	For $V = 1$ Value of V_a is	For $V_a = 1$ Value of V is
1	0.98	1.02
2	0.961	1.04
3	0.943	1.06
4	0.926	1.08
5	0.91	1.1
6	0.89	1.12
7	0.87	1.14
8	0.86	1.16
9	0.84	1.18
10	0.833	1.20

II. Curvature Myopia

Degree of Myopia (R) in Diopters	For $V = 1$ Value of V_a is	For $V_a = 1$ Value of V is
0.2	0.80	1.25
1	0.762	1.31
2	0.756	1.3226
3	0.754	1.3261
4	0.753	1.3279
5	0.7525	1.3289
6	0.7520	1.3297
7	0.751	1.3304
8	0.75	1.3305

III. Axial Hypermetropia

Degree of Hypermetropia (diopters)	For $V = 1$ Value of V_a is	For $V_a = 1$ Value of V is
1	1.02	0.98
2	1.04	0.96
3	1.06	0.94
4	1.08	0.92
5	1.11	0.90
6	1.13	0.88
7	1.16	0.86
8	1.19	0.84
9	1.22	0.82
10	1.25	0.80

IV. Curvature Hyperopia

Degree of Hypermetropia (diopters)	For $V = 1$ Value of V_a is	For $V_a = 1$ Value of V is
0.5	1.625	0.616
1	1.55	0.643
2	1.526	0.655
3	1.517	0.659
4	1.512	0.661
5	1.510	0.662
6	1.508	0.663
7	1.507	0.6635
8	1.506	0.6639
9	1.505	0.6642
10	1.50	0.6644

PART FOUR

BINOCULAR VISION AND OCULAR MOVEMENTS

XIX. FUNDAMENTAL PRINCIPLES OF OCULAR ROTATIONS AND MOVEMENTS

315. *Center of rotation of the eyeball.* It is important that the position of the center about which ocular movements occur should be understood as definitely as possible before proceeding to a discussion of these movements. Different competent observers, including Mueller, Volkmann, Donders, Valentin and Barrow, have given considerable attention to this subject: their results are not entirely uniform but approximate each other. The earlier experimenters placed the center of rotation very nearly at the center of the optic axis. Volkmann, as a result of his researches upon the crossing of the lines of direction (center of similitude) believed that this point was situated at the center of the axis of the eye or 12.5 mms. behind the apex of the cornea. Helmholtz and Barrow obtained results in accord with those of Volkmann. Donders concluded that the distance at which the center of motion lies behind the cornea must undergo modifications depending upon the degree and kind of ametropia, recognizing as he did the fact that ametropia depends principally upon a difference in length of the visual axis. In conjunction with Doyer, Donders instituted researches from which the conclusion was drawn that in the emmetropic eye the center of motion is situated at a distance of 1.77 mm. behind the middle of the visual axis. Assuming the length of such an eye to be 23.53 mms., the distance of the center of motion

behind the apex of the cornea averaged 13.54 mms. and in front of the posterior surface of the sclera 9.99 mms. The subjoined table gives the average of results obtained by Donders for emmetropic, myopic and hyperopic subjects.

	Length of Visual Axis (mms.)	Position of the Center of Motion			
		Behind Cornea	In Front of Posterior Surface of Sclera	Behind Middle of Visual Axis	Angle Between Visual and Optic Axes
Emmetropia	23.53	13.54	9.99	1.77	5.1°
Hyperopia	22.10	13.22	8.88	2.17	7.55°
Myopia	25.55	14.52	11.03	1.55	2°

Donders' method consisted essentially in finding out how great the angles of motion must be, with equal excursions on both sides, in order to make the two extremities of the measured horizontal diameter of the cornea coincide alternately with the same point in space. This means that he determined the center of rotation by procuring the elements of a triangle of which one side, the diameter of the cornea, was known. The diameter of the cornea was measured by the aid of the ophthalmometer of Helmholtz, the flame of the lamp being placed perpendicularly above the instrument, and its image as reflected from the cornea viewed through the ophthalmometer. The cornea was illuminated by a separate lamp screened from the instrument. The eye under investigation was given a definite direction by fixing a sight or mire which was movable: thus it was possible to bring the eye into such a position that the reflected image of the lamp appeared exactly at the center of the cornea. The ophthalmometric images being doubled, it was possible to make the images of the flame fall upon the extreme border of the two images of the cornea. The number of degrees required to bring the double image into this position gave one-half of the chord subtending the cornea. It was then necessary to ascertain the arc which the cornea must describe in traversing this known distance, i. e , its own transverse diameter. In order to make this measurement a ring was suspended before the examined eye. It carried a fine hair placed perpendicularly. The number of degrees the eye must be moved in order that the hair should appear first at one and then at the other margin of the cornea was found; this number of degrees corresponded to the angle which the eye had described from its center of rotation. This angle in normal eyes was found to be about 50°. The knowledge of the half-diameter of the cornea and

of the above range of motion then permitted of a determination of the center of motion; for if we call "p" the semi-corneal chord, "y" the half angle of motion and "x" the distance from the center of motion to the corneal chord we know that $p = x \tan y$. Giraud-Toulon criticized these measurements of Donders, saying that he assumed the very point in question. Mauthner later obtained results in fair agreement with those of Donders. *The eye, therefore, rotates about a point approximately at its geometrical center or the mid-point of its optic axis.* It possesses no translation, however, properly speaking: for if we regard the head as fixed and confine our attention to a study of the voluntary movements of the eyeball we find it approximately true that translation of the globe is prohibited by virtue of its attachments to the orbit. Since, however, the evidence is reasonably conclusive that the center of rotation of an eye is a trifle back of the geometrical center of the eyeball, it follows that the globe is slightly translated in whatever direction the eye is made to turn. Maddox says that in maximum excursions of the eye this translation is probably not less than one or greater than two millimeters. (For detailed mathematical and experimental proofs see Howe's *Muscles of the Eye,* Vol. I, pages 123-126, and an article by Ferree and Sheard on "Ocular Movements and the Center of Ocular Rotation," *Journal of Ophthalmology, Otology and Laryngology,* 1916.)

316. *Individual ocular muscles and planes.* All the rotations of the eye occur, then, about a fixed point known as the center of rotation. The six muscles which contribute to these rotations are divided into three pairs and each pair acting by itself causes the eye to rotate upon a definite axis which in every instance cuts the center of rotation. The plane of action of the *rectus internus* and *rectus externus* may be regarded as practically identical although from observations by Fuchs and Stevens we may conclude that there are variations from the ideal insertions and therefore variations from the rotations according to the rule. Hence the axis of turning for the eye under the influence of the externus and internus is vertical and by the action of the lateral muscles the eye will be turned exactly upon this axis and the axis will not be forced from its original vertical position.

317. As in the case of the lateral muscles, so also is the plane of action of the *superior* and *inferior* recti practically common to both. Unlike the lateral recti, however, the course of the superior and inferior recti is not parallel with the antero-posterior axis of the eye. Inasmuch as the center of traction from the insertion, both for the superior and for the inferior, is nearly at the point cut by a sagittal plane through the center of the eye and since the line of action in each case

is inward, it follows that this line of traction will not fall through the center of rotation but to the inner side of it. Due to this arrangement, therefore, it will be seen that if all the other muscles were at rest while the vertically acting muscles were in active and equal contraction, the eye would be rotated upon the vertical axis inward. The horizontal rotation axis for these two muscles cuts the optic axis obliquely. This rotation axis is at an angle of 70° in relation to the line of regard as determined by Ruete. Mauthner makes the angle with the transverse axis about 30°. This axis of rotation then points outward and backward and inward and upward and lies in the horizontal plane when the eye is in its primary position. But the action of these two muscles upon the eyeball cannot be uniform under all conditions: for in the primary position the axis of rotation for these muscles is at an angle of about 30° with the transverse diameter of the eye while as the eye leaves the primary position through, for example, the influence of the lateral muscles, the relations between the axis of rotation and the transverse axis of the eye must change. Hence a change of the direction of the optic axis outward 30° would bring this axis and the axis of rotation into coincidence so that in this position the action of the two muscles together would neutralize each other or, separately, one would roll the ball directly upward and the other directly downward without rotation on the optic axis. If, on the other hand, the eye could be turned *in* about 60°, the muscles would exercise their traction directly around the antero-posterior axis and acting together would rotate it inward, while acting separately they roll it upon this axis without modifying its direction. Hence at all points intermediate to these extreme positions the eye not only experiences a change in direction of its optic axis due to the separate action of these muscles but it must also be revolved upon the optic axis as a wheel upon an axle. The extent of this revolution must be dependent upon the angle between the axis of action of the two muscles and the transverse axis of the eyeball. If, then, as Stevens remarks, "There were to be found upon the cornea a vertical white line, this line, when the eye would be turned from the primary position inward (through the action of the internus) and upward (through the influence of the superior rectus) would be observed not only to move inward and upward with the general movement of the eye, but to tilt with its upper end inward and the farther the eye were to turn inward the more would the originally vertical line lean toward the median line of the face." The turning of the eye under the externus and superior would produce like results but with a tilting of the vertical line outward. These rotations of the eyeball about its own fixation line under

the influence of contractions of the muscles are known as *torsions:* we shall discuss them further under *Listing's law.*

318. The third pair of muscles, *the obliques,* have approximately a common plane of action and like the other pairs of muscles they are mutually nearly antagonistic. Their axis of rotation is, like that of the superior and inferior recti, horizontal and this axis forms with the line of regard, according to Ruete, an angle of about 35°, according to Volkmann about 39° and according to Mauthner about 42°. These muscles, acting together against the center of rotation, rotate the eye inward; singly the action changes. Stevens says that it is questionable whether the first part of the preceding statement is correct; their combined action does, however, sometimes force the eye forward. Each of these muscles, acting individually, swings the anterior pole of the eye outward; the contraction of the superior oblique, when the head and eyes are in the primary position, causes the anterior pole to describe a curve downward and outward, while the contraction of the inferior oblique gives an outward and upward movement. The most notable result of the action of these oblique muscles is the rolling of the eye upon its antero-posterior axis. This action is similar to that of the superior and inferior recti but more pronounced; the action of the superior rectus, for example, draws the eye upward and inward and tilts the upper end of the vertical meridian of the cornea inward while the superior oblique, acting singly. turns the eye downward and outward and gives the vertical corneal meridian an inward turning of its upper end. A similar comparison can be made of the actions of the inferior rectus and inferior oblique.

319. As in the case of the vertical muscles, we find that the effective action of the obliques varies with the position of the line of regard with respect to the primary position. As the line of regard is carried to the temporal side their influence becomes less upon the rotations laterally and vertically while the torsion becomes greater, while as the line of regard is shifted to the medial side the influence of these muscles becomes greater in vertical movements as the degree of turning inward increases, while the torsion is proportionately reduced.

320. The muscular planes and axes of rotation for the vertical recti and the obliques are diagrammed in Fig. 166. The letters *R,R* refer to the muscular planes and *r,r′* to the axes of the recti, while the letters *O,O* and *o,o′* refer to corresponding terms for the obliques.

As to the primal muscular functions, then, we find that each eye possesses one muscle pre-eminent for abduction, namely the external rectus; another for adduction, the internal rectus; for elevation or supraduction, the superior rectus; for depression, infraduction or

subduction, the inferior rectus; for intorsion, the superior oblique and for extorsion, the inferior oblique. In addition to these prime actions each muscle has secondary actions; this secondary action is a minimum with the lateral muscles which are purely adductors and abductors respectively except possibly when the eyes are elevated or depressed. We may say in brief summary that the superior muscles cause intorsion and the inferior muscles extorsion; the obliques abduction and the recti (superior and inferior) adduction as *secondary* or *subsidiary* actions.

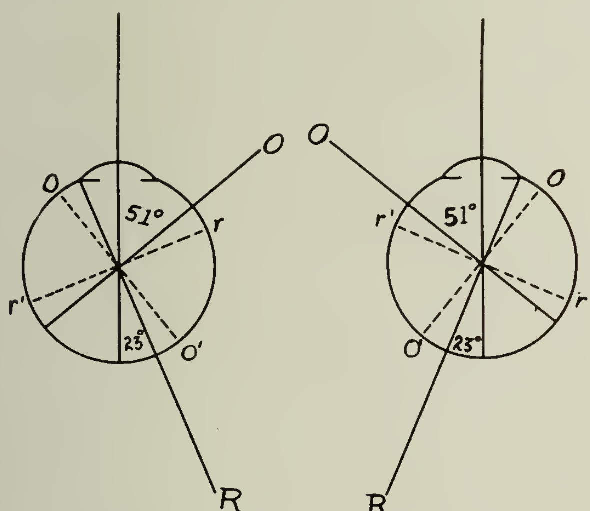


Fig. 166.—The Muscular Planes and Axes.

O—The muscular planes and oo′ the axes of the obliques. R, R—The muscular planes and r r′ the axes of the recti: O, O and o, o refer to the corresponding planes and axes for the oblique muscles.

321. *False torsion. Listing's law. Donders' law.* Donders observed that each time the visual regard returns to the same point, no matter in what way, the eye always reassumes the same position. If, for example, by fixing a colored ribbon stretched horizontally there is produced thereby an after-image which is then projected onto a wall, then, keeping the head motionless, it is found that the image assumes a position which is not in general horizontal but which is always the same every time that the visual regard returns to a given point. In other words, Donders observed that whatever position the eyeball may take there belongs to that position a definite amount of torsion which remains the same no matter how often the eye may return to that position and however many motions it may make in arriving at

it. He says: "For any determinate position of the line of fixation with respect to the head, thereto corresponds a determinate and invariable angle of torsion, a value independent of the volition of the observer, independent also of the manner in which the line of fixation has been brought into the desired position." Helmholtz has stated the same law more concisely as follows: "The wheel-movement of each eye is, with parallel fixation lines, a function only of the elevation angle and of the lateral deflection angle."

322. Experiment has shown that one degree of freedom is lost in all voluntary movements of the eyes which start from the straight-forward position; latent torsion is not voluntary however. The degree of freedom which is lost is that of rotating about the antero-posterior axis considered as fixed in the head, the two degrees of freedom remaining being those of rotation about vertical and transverse axes. Simultaneous rotations about the vertical and transverse axes can be variously compounded into rotations about any intermediate axis. This amounts to saying that they are limited to rotations about all conceivable diameters in one plane, which is that plane containing the vertical and transverse axes and which is called or known as Listing's plane. Listing's plane passes through the center of motion of the eyes and is a vertical transverse plane fixed in the head and perpendicular to the fore-and-aft axis, about which no rotation can take place. When the head is erect and the eyes look straight forward at a very distant object on the horizon they are generally said to be in their *"primary position."* No matter, then, how many or complex the motions of an eye may be in glancing from point to point, the ultimate result is equivalent to a single rotation of the globe about some axis in Listing's plane provided the eye started from the primary position. The primary position of the eye is practically identical with the equatorial plane of the eye.

323. To revert again to Listing's law, it is to be said that this law goes a step further than that of Donders' and is as follows: "When the line of fixation passes from its primary to any other position, the angle of torsion of the eye in this second position is *the same as if* the eye had arrived at this position by turning about a fixed axis perpendicular to the first and second positions of the line of fixation." According to this law, therefore, an eye may be brought from the primary position to any secondary position by a rotation around an axis perpendicular to the two successive directions of the visual line. Listing's law means that when the eye starts from the primary position and glances toward an object situated obliquely, the line of fixation takes the shortest possible cut to its new position and must,

therefore, move along a plane common to its original and its new position. In order that this may be accomplished, the eyeball must rotate around an axis perpendicular to this plane and hence perpendicular to the line of fixation throughout the whole of its motion. This law is likewise essential to the rapidity of the ocular movements. "The exquisiteness of this design is apparent," says Maddox, "when one considers that no fewer than three muscles are concerned in every oblique motion of the globe, not one of which, acting individually, would rotate the eye about the required diameter." Certainly the arrangement on which Listing's law is based entails an absolute minimum of motion, hence it results that the momentum of the ocular contents is the least possible, the time is the shortest, the work done is the least and the lowest kinetic energy is developed.

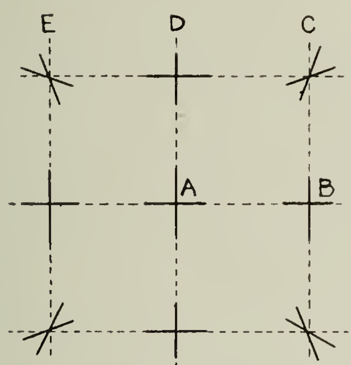


Fig. 167.—Demonstration of Law of Listing.

324. *Ruete's demonstration of Listing's law.* In the method, due to Ruete, the observer places himself at a distance of one or two meters from a wall on which is placed a fixation point A (Fig. 167) on a level with the eyes. A head-rest similar to that used on the ordinary ophthalmometer or better yet the planchette of Helmholtz enables the subsequently taken measurements to be obtained with fair accuracy. At the fixation point A (Fig. 167) is placed a cross with its arms horizontal and vertical. This cross ought to contrast boldly with the background; red on a gray is very satisfactory. With the head properly fixed it is possible to find a position such that, on moving the gaze along the prolongation of each of the arms of the cross, the after-image of this arm glides upon itself as indicated by the dotted lines. When this position is found the planchette is rigidly fixed in order that the observer may be able at all times to return to this condition in which, when the point A is fixed, the eye is in its

primary position. In fixing, then, a point B, situated on the prolongation of the horizontal arm, the eye has moved in its primary plane and hence it is apparent that the gaze may be swung from A to B by a motion around the vertical axis, which is an axis perpendicular to the two positions of the visual line. The same is true for displacements in the vertical direction. But if, in these experiments, the gaze is directed along the prolongation of the arms of the cross we observe phenomena which are apparently at variance with Listing's law. For if the observer, after raising his gaze, were then to turn his eyes to the right, as at C in the accompanying figure, the after-image would no longer remain vertical but would slope to the right; and again on looking to the left, as at E, it would slope to the left. There is then a rotation of the after-image. Hence it appears that this is a simple consequence of the law of Listing and that the meridian which was vertical when fixing A cannot remain vertical when the eye turns around an axis perpendicular to the direction AC. It can be experimentally demonstrated that the law of Listing is also verified in cases of oblique displacement by tilting the cross represented in Fig. 167 so that its arms are not vertical and horizontal but make an angle of 45 degrees with these directions. It can then be shown that the after-image of one of the arms of the cross glides all the time on its prolongation, hence the eye turns around an axis perpendicular to this meridian. In the experiments recorded above relative to the sloping of the after-images when gazing obliquely it might be concluded that when the eyes occupy oblique positions they experience torsion equal to that of the after-image. But since those portions of the wall upon which the after-images fall are not perpendicular to the line of sight, these slopes are exaggerated. As a variation of the experiment, let the head be rotated considerably to the left and kept temporarily fixed in that position. Then, after gazing at the cross or ribbon, turn the eyes up the wall immediately above the fixation object and the image will appear to become more twisted to the right the higher the gaze is raised. This proves that torsion does take place on looking up and to the right. But this experiment, though it correctly indicates the presence of torsion and the true sense in which it occurs, does not measure it correctly since there is not perpendicularity of plane and visual line in the secondary position. Le Conte remedied these defects by placing an experimental plane in such a way that the line of sight is at right angles to this plane when the gaze is turned up and out, down and out and so on, and thus obtained results uniform with the laws of torsion in all positions. To obtain correct results it is necessary either that the *accidental*

images be projected upon a surface which is in every case at right angles to the line of regard, that is, upon the inner surface of a sphere at the center of which lies the eye, or that the plane upon which the observations are made shall be marked with lines representing a series of spherical coordinates. The diagram in Fig. 168, due to Helmholtz, shows the inclinations for the horizontal and retinal images for different positions of the line of regard when the secondary image is projected upon a plane vertical surface. Hence, when the line of regard is elevated and directed to the right the accidental image tilts to the left; when directed to the left, the image tilts to the right;

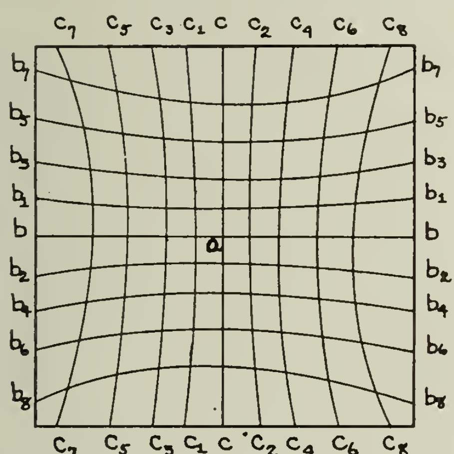


Fig. 168.—Inclination of the Horizontal and Vertical Images when Projected upon a Plane Wall.

If *a* is the first point fixed, the accidental image, as the regard passes from *a* to some other point, the position of the accidental image will conform to the direction of the line on which the regards rest. (Diagram from Helmholtz: description taken from Stevens.)

when the line of regard is depressed and directed to the right the accidental image tilts to the left and when directed to the left the image tilts to the right.

325. If the gaze then passes from one secondary direction to another the position of the eye is determined by the law of Listing since, having reached its new secondary position, it must have the same position as if it had arrived there starting from the primary position. For if the gaze passes from *B* to *C*, Fig. 167, following the prolongation of the vertical arm, it is observed that the after-image of this arm starts from the prolongation and rotates more and more so as to attain the position which it should have when the gaze has arrived at *C*. In

making this movement the eye does not rotate around an axis perpendicular to the visual line. If the line of regard is so displaced that the after-image moves at all times upon itself, then the point of fixation describes a curve the convexity of which is turned towards the point A. The same is true for the horizontal arm; if the point of regard moves from C to E, Fig. 167, so that its after-image moves on itself there is obtained a curve with its convexity downward. These statements are in agreement with the curves shown in Fig. 168. The following illusion, described by Helmholtz, is explained by the foregoing observations. If, after having fixed the point A in the primary position, the eyes are raised and survey quickly a horizontal line situated in a higher plane it will appear concave toward the floor. This may be explicable on the basis that oblique directions of the gaze are uncommon; when we desire to look at any object we ordinarily turn our heads in such a manner that the eyes are nearly in their primary position so that horizontal lines lie on the horizontal meridian. On account of this habit there is a tendency to consider the horizontal retinal meridian as horizontal even when it is not so.

Hence, in any of these movements which we have been considering, what we call the vertical axis at one instant ceases to be the vertical axis as soon as the globe has changed its position; the result is an apparent rolling of the globe although not a true wheel motion. This movement has been called by Maddox and other writers ''false torsion'' to distinguish it from the true wheel motion.

326. In order to get a clearer notion of the motions of this group it is desirable to make use of some form of ophthalmotrope. A simple rubber ball pierced by three needles at right angles to each other answers admirably. This should be modified or added to as follows: (1) Attach a thread to the anterior polar axis at its point of emergence from the globe. Make the thread a little longer than the radius of the circle representing the cornea and to the loose end of the thread attach a small weight so that this may act as a plumb-line. (2) Mark off about thirty degrees at the lower edge of the circle which indicates the edge of the cornea or any other circle on the eye concentric with it. (3) Transfix the ball with another needle which is to constitute the axis upon which the globe revolves into the oblique position. When the visual axis (the antero-posterior axis) is made to pass upward and outward, for example, the plumb-line shows that the originally vertical axis in the primary position no longer remains so but that another axis which marks another vertical plane has taken its place. The number of degrees between the two positions occupied by the plumb line indicates the amount of false torsion. These effects can

also be illustrated in a very simple manner by a circular disc of cardboard as suggested by LeConte and elaborated upon by Maddox. LeConte says:—"A simple experiment will show the kind of rotation which takes place in bringing the eye to an oblique position. Take a circular card, Fig. 169, and make on it a rectangular cross which shall represent the vertical (*VV*) and horizontal (*HH*) meridians of the retina. A small circle at the center represents the pupil. Now take hold of the disc with the thumb and finger of the right hand at points *VV* and place this line in a vertical plane. Then tip the disc up so that the pupil shall look upward 45° or more but the line *VV* still remaining in the vertical plane. Finally, with the finger of the left hand turn the disc on the axis *VV* to the left. It will be seen that *VV*

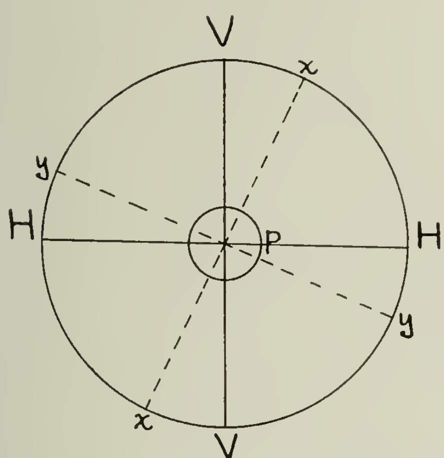


Fig. 169.—Cardboard Model to Illustrate False Torsion.

is no longer vertical, nor *HH* horizontal, but some other line *xx* is vertical and *yy* horizontal. In other words, the whole disc seems to have rotated to the left. But there is evidently no true rotation on a polar axis but only an apparent rotation consequent upon reference to a new vertical meridian of space."

327. We may, therefore, conclude:—

(1) When the eye moves from its primary position up, down, in or out no torsion occurs.

(2) When the eye moves in an oblique position the axis which is vertical in the primary position is replaced by another vertical axis, the former vertical axis now being oblique.

(3) The after-images which are projected on a flat surface are not in the same position when projected on a concave surface to which the visual axis is perpendicular.

(4) The so-called "false torsion" is not a true wheel motion of the globe.

(5) The exact amount of this torsion with parallel visual axes can be calculated for any given position of the visual axis. This was done originally by Helmholtz; his formula is

$$\tan\left(\frac{\Upsilon}{2}\right) = \tan\left(\frac{\alpha}{2}\right) \cdot \tan\left(\frac{\beta}{2}\right)$$

in which α is the vertical movement, β the lateral movement and Υ is the size of the angle of rotation. The proof of this is given in Helmholtz *Handbuch der Physiologischen Optik;* further amplifications are to be found in Howe's *Muscles of the Eyes,* Volume 1.

(6) The relation of this form of torsion to the positions of the double images seen in certain cases of paralysis is sometimes important. Suppose, for example, a paralysis of the abducens (sixth nerve) on the right side. The axis of vision of the right eye then turns towards the left or nasalward; a case of homonymous diplopia will arise. The image with the left eye is in its normal position. To a patient viewing a candle held vertically and directly in front, no torsion or tipping of the two candles as seen by virtue of the diplopia will occur. But if the candle is moved upward and to the right the image which is seen with the right eye is no longer vertical, the upper end now being tipped more or less away from the median plane. The tendency of the eye is, of course, to undergo the kind of torsion which it would if one of the muscles involved were not paralyzed. This eye in this condition acts practically independently of its mate; the degree of the paralysis together with the factors stated in Donders' law determine the amount of inclination given to the false image.

328. *The directions of the apparent vertical and horizontal meridians of the eye.* If the point of regard of the two eyes is fixed in the median and horizontal plane and at an infinite distance so that the head of the observer is in the primary position it might be assumed that the vertical meridians of each retina would coincide with the plane perpendicular to the plane of regard and that the horizontal meridians would coincide with the plane of the gaze. But the views of some of the ablest experimenters are at variance upon this proposition. Helmholtz concluded that the horizontal retinal meridians so nearly coincide with the plane of regard that they may be considered as identical, but characterized the vertical meridians as "apparent" only, for he reasoned from his own experiments and those of Volkmann that these apparently vertical meridians actually converged

downward to the extent of 1.25° for each eye in normal eyes, thus making an angle between the two vertical meridians about 2.5° with the lower extremities of the meridians approaching each other. Meissner and Hering found tiltings of the apparent vertical meridian, while LeConte found the vertical meridians to be vertical in his own case but his proof is not conclusive.

329. Tscherning has described a phenomenon, first observed by Meissner, which we encounter when we wish to judge whether a line is vertical or not. A plumb-line is held in front of a uniformly painted wall and a point situated a little in front of this line is fixed; one must take care not to approach too closely to the line else the influence of convergence will enter into this experiment. Under these conditions of fixation at a point slightly in front of the line, the line will be seen double. One would expect to see two vertical and parallel lines; the two lines, however, appear to converge upwards; seen with the right eye the upper extremity of the line seems to lean to the left according to Tscherning. If a point behind the line is fixed the images are crossed and appear to converge downwards. A vertical line seen with one eye only does not then appear vertical but its upper extremity leans either to the left or the right depending upon which eye looks at it. A rectangular cross, carrying vertical and horizontal arms, will therefore appear differently to each of the eyes, for the two angles at the upper right and lower left will appear to the right eye larger than the other two angles, while the reverse is true for the left eye. Since a vertical line appears to lean to the left for the right eye, there should exist then a line actually leaning to the right which appears vertical. That this is the case can be demonstrated by taking a white circular disc which can be rotated about its center and drawing thereon a diameter. Along the border is a scale graduated in degrees and so arranged that the zero corresponds to the position of the line when vertical. This scale must be placed so as not to be visible to the observer. The observer then states when the diameter appears vertical; it is found experimentally that in the majority of cases, using the right eye, the upper extremity will be placed some degrees too far to the right and with the left eye some degrees too far to the left. It is, of course, necessary that the experiment be arranged in such a manner that the observer cannot correlate the line with surrounding objects. In the case of the horizontal meridian the phenomenon is less apparent.

330. Volkmann has given a method of determining the apparent vertical meridians of the two eyes in which two small revolving discs are placed on a vertical support so that the distance separating their

centers is equal to the distance between the eyes. A radius was drawn on each disc and the discs placed as shown in Fig. 170. One of the discs was placed so that its radius was vertical; the discs were then observed as with the stereoscope, the right eye fixing the right object and the left eye the left object. The attempt was then made to cause the two radii to form a single straight line; it was found that they must form an angle of about two degrees before this was possible. Or, if a stereoscope is used which carries small discs like those of Volkmann and upon which are drawn radii exactly parallel, it will be found that on fusion the two discs will form but one, but the diameter appears broken.

331. It is probable that the downward direction of regard which is demanded in nearly all of our everyday pursuits may be the cause of these phenomena; certainly we are accustomed to some convergence and downward gazing in reading and near work and even in walking,

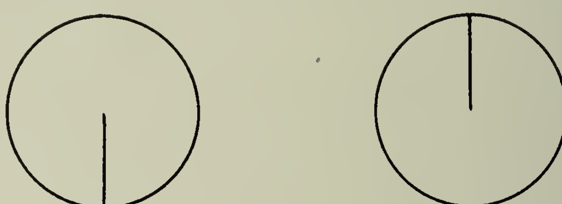


Fig. 170.—Discs of Volkmann.

when the gaze most frequently follows the ground. If the experiments of Meissner are repeated in such a manner that the lower extremity of the plumb-line is approached toward the observer until, in relation to the line of regard, this line occupies about the same position as would the page of a book when held in the customary position for reading, the two images of the line will appear parallel.

332. All of these phenomena can be readily observed by using a pencil or a hat-pin placed ten to thirteen inches from the nose and in the median plane. If the head is held in its approximately primary position and a point on a distant wall is fixed, the pencil being held in a vertical plane and placed at right angles to the direction of regard, two images of the near object will be seen and as these are allowed to slowly fuse by the voluntary control of the fusion on the part of the observer it will be found that the lower extremities of the two images will coalesce first, giving a V-shaped single image. In other words the image for the left eye will lean to the right and for the right eye toward the left. But if the pencil is held in the position in which a book is ordinarily placed with respect to the line of regard

and a distant point first fixed and the two images obtained, it will be found that, as the fusion is allowed to take place by degrees, the two images will remain parallel and that both the upper and lower extremities of the images will coalesce at the same time, as a general rule.

333. These conclusions as drawn from these experiments of Helmholtz, Volkmann, Meissner, Hering and others are not accepted by Stevens, who has done a considerable amount of careful work upon this subject and who has given us the clinoscope as one of the products of his investigations. Stevens points out as the prerequisites for determining the actual positions of the meridians, the following:—(1) A knowledge on the part of the observer of the adjustments of his own eyes with respect to heterophoria, anaphoria or kataphoria; (2) a means by which the exact position of the head may be maintained: the position described by Volkmann, Helmholtz and others is inexact, uncertain and irregular; (3) examinations in this field of inquiry are of little if of any value when the observer can see surrounding objects, and (4) when it is desirable to blend or compare test objects in the field of regard of the two eyes, as for the distant point, the blending or comparison should be made with the lines of regard of the two eyes parallel. All of these conditions for physiological research in respect to the meridians are met, according to Stevens, by his clinoscope. A modified form of instrument with short tubes, thus permitting of convergence within a few inches of the eyes, has replaced the older form of instrument. The clinoscope objectives are the Volkmann's discs shown in Fig. 170. When the observer looks into the tubes the discs blend and the two pins become one long pin with the common head in the middle. When each pin is brought into a position such that it appears to the observer to be exactly vertical and remains so it marks the position of the vertical meridian of the observer's eye as indicated by the pointer and scale above the tube for that eye.

334. Stevens is not in agreement with the views and the results of the experiments of Helmholtz and others but says: "All my experiments, which have now been continued during several years, lead to the conclusion that the typical normal position for the vertical meridians is the exactly vertical position and that the typical position of the horizontal meridians corresponds with the external horizon." Deviations from these positions when the regard is directed in the primary position are anomalies—so-called cyclophoria, or the tendency of the vertical axes to be turned inwards or outwards from the true vertical meridian. Whether or not, however, we are to assume that under normal conditions what we call the normally vertical axes are

not in reality quite vertical but that the upper end of each axis tips outward at an angle of from one and a half to two degrees from the median plane is a mooted question in regard to which we have presented some of the experimental evidence.

335. *Monocular rotation.* Monocular rotation differs in some essentials from binocular rotation: the same muscles are concerned in each but the innervations are not identical throughout. The volitional brain centers, with one exception, are alike concerned in both classes of rotation but in monocular rotations there is no *fusion* demand. To effect all possible monocular rotations the four straight muscles and the two obliques are needed. A straight muscle can effect a given rotation only when that muscle is bisected by the rotation plane from its origin to its insertion. Two muscles are required to effect a cardinal rotation and three muscles are required for any oblique rotation. While only six muscles are required to effect monocular rotation in any direction, eight voluntary centers are requisite, one center for each straight muscle and two for each oblique muscle. Only one muscle and one innervation are needed for a cardinal motion either toward the temple or the nose if the lateral recti are bisected by the plane of the horizontal retinal meridian. Two muscles and two innervation centers are necessary if the visual axis is to be rotated in the plane of the vertical meridian. If the visual axis is to be rotated in the plane of any oblique meridian this must be done under the simultaneous and harmonious action of three muscles under impulses from three volitional centers. One of these muscles, the oblique, will prevent any rotation on the visual axis while it is being rotated in the rotation plane by the other two muscles around two moving axes, these axes being always the transverse and vertical axes of the eye. These three forces combined (not converted into one force, however, in the sense of creating a fixed axis) rotate the eye in an oblique plane without torsioning just as if the eye had been rotated first on the vertical axis to a point in the horizontal plane directly beneath the secondary point and thence directly up around the transverse axis of the eye to that point. These preceding statements constitute the essentials of the views of Savage as expressed in the opening chapter on the fundamental principles of ocular rotations in his *Ophthalmic Myology.* He gives the following as his formulation of the law of monocular motion. "(1) The visual axis, which is the line of intersection of all the planes of all meridians, must be rotated in the plane of that meridian on which lie the first and second points of view and their retinal images. (2) In the plane of the horizontal, or that of the vertical, meridian, the rotation must be effected around a single fixed axis at right angles to

the rotation plane and cutting it at the center of rotation—if in the horizontal plane, around the vertical axis of the eye; if in the vertical plane, around the transverse axis of the eye. (3) In the plane of an oblique rotation, whatever the degree of obliquity, the rotation must be accomplished around two moving axes by two forces acting simultaneously, these axes being the transverse and vertical axes, both at right angles to the visual axis, but neither one at right angles to any oblique rotation plane; while a third force prevents any rotation around the visual axis." As Savage remarks, the third portion of this law is open to controversy, since it denies the possibility of a resultant fixed axis. The purport of this statement is that, while the visual axis is being rotated in a given plane, the vertical axis of the eye shall never lose parallelism with the median plane of the head. Hence, Savage says, "Listing's plane cannot be a plane of reference, nor can it be a plane containing the axes of all rotations starting from, or returning to, the primary point of view. The equatorial plane of the eye contains both the vertical and transverse axes of the eye and it is around one or the other or both of these that all rotations, cardinal and oblique, occur. Listing's plane, like Listing's law, should be forgotten in the interest of truth."

336. These opinions of Savage are presented ahead of the more commonly accepted notions of the actions of the associated muscles in a single eye because of their simplicity and because they are at variance with a considerable number of orthodox views. The ordinarily accepted ideas upon the composition of rotations treat them in a manner analogous to the composition *of forces* in physics. The amount of rotation imparted to a rotating body can be represented in linear measure by laying off along the axis a distance proportionate to the rotation. Since a body can rotate in two directions about any axis it is necessary to choose one diameter to represent rotation in one sense and the other direction to indicate rotation in the opposite direction. By a single measured line it is, therefore, possible to represent three quantities: (1) the axis of rotation, by the direction of the line; (2) the amount of rotation, by the length of the line, and (3) the sense of the rotation by the direction from the center in which the line is drawn. Any units may be chosen; millimeters may represent degrees. Since the forces acting upon an eye through the muscles in the interest of ocular rotation are tangential and since the lines of the forces may, with little error, be reckoned as equally distant from the center of rotation it follows that the moments of the forces, which are a measure of the tendency to produce rotation about any point, may be taken proportionate to the forces. Doubtless the resistances

to rotations of the eyeball are greater in some directions than in others, but this element of resistance cannot be calculated, hence the forces can be measured only by the rotations which they produce. Therefore, rotations and not forces must be compounded, since the forces are not known but the rotations can be investigated to a goodly degree of accuracy by the behavior of after-images. In the accompanying diagram (Fig. 171), let C represent the center of rotation. The arrowheads on the lines Ca and Cb represent the directions in which the lines are measured and therefore the direction of the rotation which takes place about each as an axis and which is the same as that of an ordinary screw turned right-handed in the direction of the arrow. These two forces, Ca and Cb, when compounded give the resultant Cd by the method of the parallelogram. The reason for the composition of the rotations is fairly obvious: for if the body were subjected to one of the rotations any point in it would move over a

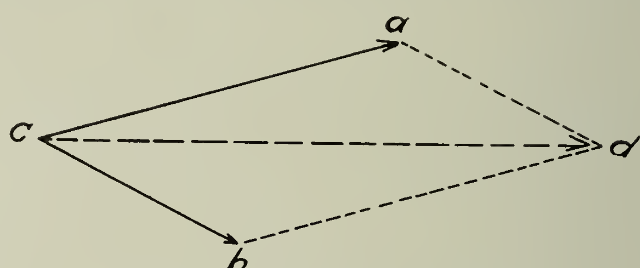


Fig. 171.—Composition of Rotations.

distance proportional to the amount of rotation and to the distance from the axis of rotation. When the rotations Ca and Cb take place simultaneously, points which lie between their axes will rise in consequence of one rotation and sink because of the second; the line Cd represents the locus of points such that the rising and falling exactly neutralize each other. The distance of each point in the line Cd is inversely proportional to the amount of rotation about the axes.

337. These principles are applied to the rotation of the eyeball as illustrated in Fig. 172. This represents a horizontal section of the eye with A and P the anterior and posterior poles of the eye, so that AP is the optic axis. The line DE is the transverse axis: MN is the axis of rotation of the superior and inferior recti and M^1N^1 is the axis of rotation for the obliques. A measured quantity, Or, along the line ON indicates a measured rotation of the globe in the sense of a screw proceeding from O to N. This rotation elevates the cornea and

would be effected by the superior rectus acting alone if this were possible. Similarly Os specifies a proportionate rotation by the inferior oblique which also elevates the cornea. These rotations (Or and Os), when they occur simultaneously, are compounded into a single rotation OE which takes place about an axis in Listing's plane.

338. We may likewise resolve rotations due to individual muscles. Taking the inferior rectus as an example, let the distance OM represent the maximum rotation it can produce. By dropping perpendiculars from M upon the transverse and optic axes we find that these perpendiculars cut off distances from O along these axes which give the component depression and torsion respectively. Om represents

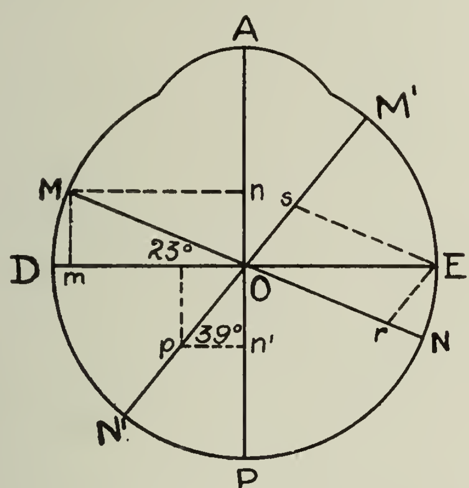


Fig. 172.—Horizontal Section of an Eye to Illustrate Composition of Rotations.

the depression of the cornea and On its torsion or extorsion. The lengths of these two lines are readily found trigonometrically; if we take the obliquity of the axis of the superior and inferior recti as 27° from the transverse axis, the component Om will be 0.89 or about nine-tenths of the whole rotation, OM, and the component On will be 0.45 or about nine-twentieths of the whole rotation about OM. Hence the elevating action is double that of the torsional effect.

339. We are, finally, desirous of finding out how much rotation the superior oblique must effect in order to be a perfect associate of the inferior rectus. If, then, subduction is to be unaccompanied by torsion, the extorsion On must be offset by an intorsion On_1. Marking off, therefore, On_1 equal to On but in the opposite direction from O, erect a perpendicular to the axis AP at the point n_1: where this

line cuts the axis of rotation of the obliques (ON_1) gives the direction Op indicating the exact proportion of intervention needed on the part of the superior oblique, since the torsional component On_1 balances the torsional component On of the superior rectus while the subducting component n_1p supplements the subduction of the rectus. As a matter of fact the lengths Om and n_1p represent the relative proportion of subduction due respectively to the inferior rectus and the superior oblique; the latter is about two-fifths of the former.

340. As Maddox, from whom the essentials of the above treatment of monocular motion is taken, remarks: "These calculations are at best only approximate but we can by their aid determine with more or less approach to truth the provinces of the motor field over which different muscles hold sway."

341. *Binocular rotation. Conjugation of the eyes. Conjugate innervations.* The relative movements of the two eyes are governed by the desire for and necessity of seeing the object single; the two eyes are so placed and so adjusted as to make binocular vision possible in obedience to the law of corresponding or identical points. It is necessary, therefore, that an image of the object fixed be formed on each fovea. When the point of regard is changed the two eyes make associated movements: both turn to the right or to the left, upwards or downwards, and so on. If the objects are in the median plane but at different distances it is necessary that the eyes make a movement of convergence in order that the point of regard be changed from the more remote to the nearer object; both eyes normally turn inwardly to the same extent. If, however, the two objects are in different directions one being, for example, farther to the right than the other, but at different distances from the eyes, then the eyes execute a combined movement of association and of convergence; if the second object is more remote than the first object viewed there is a movement of divergence, i. e., a relaxation of convergence.

342. A movement of one eye can be made, however, without an apparent conjugate movement of its mate: in the last analysis, however, it can be shown that it is impossible to cause a movement of one eye without a motion of the other also or at least a tendency on its part to move. Hering has described a simple experiment which is of importance in understanding the relation between the movements of the eyes. Suppose the two eyes to fix a point P and that there is placed in the visual line of the right eye an object O. If the party under observation fixes the object O by changing his point of regard from P to O, the left eye will be moved toward the point O while the right eye remains motionless. But upon close observation it is found that

this eye (the right eye) in reality makes two slight changes of position, for instead of receiving no innervation, as is apparently the case, its muscles receive two innervations one of which would cause it to make an associated movement to the right and the second of which would cause it to execute a movement of convergence to the left: the net result of these innervations neutralize each other so that the eye remains stationary.

Binocular rotation is the rotation of the two eyes in the interest of binocular single vision and correct orientation; binocular single vision is possible in obedience to the supreme law of corresponding retinal points. We shall pause at this juncture to ask the question, "What is the fundamental fact of corresponding retinal points?" and to indicate various opinions and conclusions which have been formulated in answer thereto.

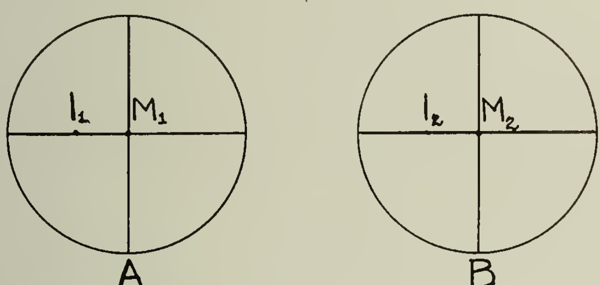


Fig. 173.—Mercator Projection of the Two Retinæ, Showing Corresponding Retinal Points According to the Accepted Doctrine.

343. *Corresponding retinal points.* This doctrine as it is commonly accepted and expressed in treatises on physiologic optics may be stated somewhat as follows. If the image of a given point is located at the temporal side of the macula of the right eye the impression will also be located at the nasal side of the macula of the left eye and at a distance from it equal to that of the impression of the right eye from the macula. Likewise, if the image is impressed at an horizon above that which passes through the maculæ or below that horizon, then the impression for each eye will be equally above or below this horizon. These points are, therefore, not anatomically but rather geometrically similar. This is diagrammatically represented in Fig. 173. Let A and B represent the two retinæ and M_1 and M_2 the maculæ. If the selected image is located on the retina A at I_1 (i. e., the temporal side of the macula) it will be located at the point I_2 of the retina B (at the nasal side of the macula) and at the same distance from M_2 as I_1 is

from M_1. It is evident, of course, that the two retinal images are in widely different localities anatomically. They are, however, not only equally removed from the maculæ but they lie on corresponding horizontal meridians of the two retinæ. Also, if the point I_1 is situated on a horizontal meridian above or below the meridian of M_1, the point I_2 will be on a horizontal meridian equally above or below the meridian of M_2. Hence we may say that a point on one retina *corresponds* or is *identical* with a point of the other one when the images of the same exterior point falling on the two retinal points are seen as a single

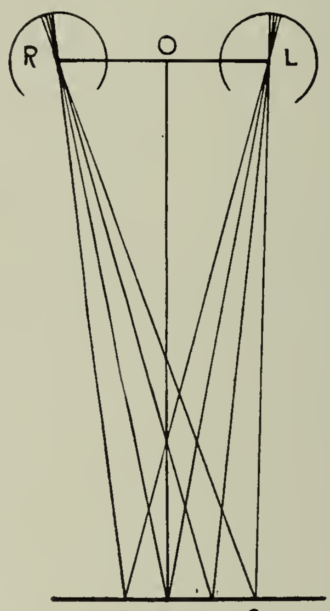


Fig. 174.—Diagram Illustrating Contention that Retinal Corresponding Points are not at Geometrically Equal Distances in the Two Retinæ. (After Stevens.)

image. If, on the other hand, the image is formed on any other point it is not blended with that of the first eye and the point is seen double. Helmholtz stated the law of corresponding points as follows:—"Upon the apparently vertical concordant lines of the two eyes, points which are at equal distances from the horizontal meridians are corresponding points," and "Points which in the retinal horizons are at equal distances from the point of fixation are corresponding points." With respect to corresponding points in the field of vision he says: "Corresponding points in the two visual fields are those which are at equal distances and equal in direction from the corresponding horizontal

and apparently vertical meridians." Stevens has criticized these statements of Helmholtz and holds that the propositions are inconsistent with the illustrations given and states that one of the most conclusive proofs that retinal corresponding points are not at geometrically equal distances in the two retinæ is that a straight line drawn in the vertical or horizontal direction does not appear curved as it would positively do were the accepted doctrine correct. Fig. 174 taken from Stevens' work, is offered by him in support of the contention "that the accepted view that the points of retinal correspondence are, by superficial measurement, equal is incorrect." In this diagram, R and L are the nodal points of the two eyes and A the point of fixation. The points B, C, and so forth are outside the point of fixation. If, therefore, $RO = 1.25$ inch and $AO = 15$ inches, then the angle $RAO = 4° \ 45' \ 49''$ and we find that the angle $ARB = 1° \ 53' \ 26''$, $ALB = 1° \ 54' \ 5''$, $ARC = 3° \ 46' \ 1''$ and $ALC = 4° \ 39' \ 58''$. The points corresponding to the incidence of the lines CR and CL are not thus equally removed from the maculæ.

344. There is a mental cognizance of relations of distances in space and distances on the retinal surfaces, but they are recognitions of *angular* rather than of equally removed spatial values on the two retinæ. Stevens, then, sums up his conclusions respecting this subject in the following statement:

"Corresponding points are those points in the retinas which answer to proportionate degrees of rotations of the eyes about their centers of rotation and which, from given points in the plane of the point of fixation, receive incident rays which must pass through the nodal points."

345. The question as to *why two points are corresponding* and two others are not has been considerably discussed. Most of the advocates of the theory of identity suppose that there exists an anatomical relation between the two corresponding points. They suppose that the nerves carrying the impressions of two corresponding points unite on their way to the chiasma into one which conducts the impression to the brain. Savage believes that the secret of corresponding retinal points is common brain-cell connection: that one macula corresponds point for point with the other macula only because these corresponding points have, going from them, two fibers which meet in the optic tract and which go, side by side, into the same cuneus to terminate in one common cell in the visual center. This explains double impressions yet a single sensation—two images, yet a single object. The theory of projections, in which impressions on the nasal side of the macula are referred in space to the temporal side and so forth, has

been advanced as an explanation by others. In this theory a point on the left retina, for example, situated 10 degrees to the left of the fovea, localizes its impression at 10 degrees to the right of the point of fixation: the point situated at 10 degrees to the left of the right fovea localizes its impression in the same direction and as the two impressions are localized in the same direction they are blended into one. This bases the whole theory of corresponding points upon experience: in fact, the identity of the two foveas might be a result acquired by experience. But according to Savage the law of visible direction does not explain corresponding retinal points: for this law, he says, is violated in the interest of binocular single vision whenever a prism is placed before either of the two eyes and that duction is possible only

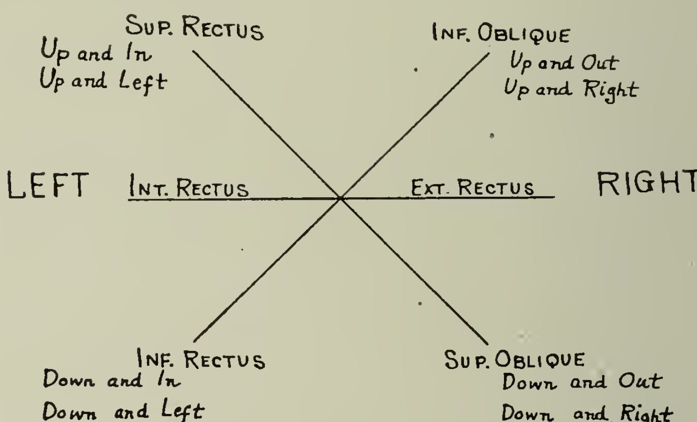


Fig. 175.—Showing Dominant Action of the Muscles of the Right Eye.

in violation of the law of direction. This objection does not appear to the writer as valid however, since in duction tests it is the function of the extra-ocular muscles to keep the eyes in such positions that the impressions of objects in space are received upon their foveas; when this is the case there follows a mental interpretation of singleness of object irrespective of the directions of the rays of light within the eyes.

346. *Conjugate innervations.* The presentation of the essential facts relative to the motions of one eye under the caption *Monocular rotations* has, of necessity, included much which relates to the motions of both eyes. Any study of the motions of both eyes is, then, rather a study of their action together in associated movements. It is known that the externi and interni have purely lateral action; that the superior rectus moves the eyeball upward and medianward; that

the inferior rectus draws the eyeball downward and medianward; that the superior oblique moves the cornea downward and temporal-

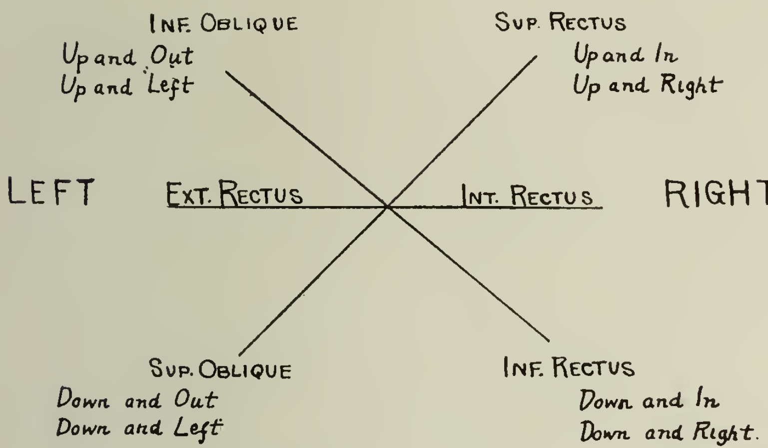


Fig. 176.—Dominant Action of the Muscles of the Left Eye.

ward, while the inferior oblique moves the eyeball upward and temporalward. Figs. 175 and 176 diagram the dominant action of

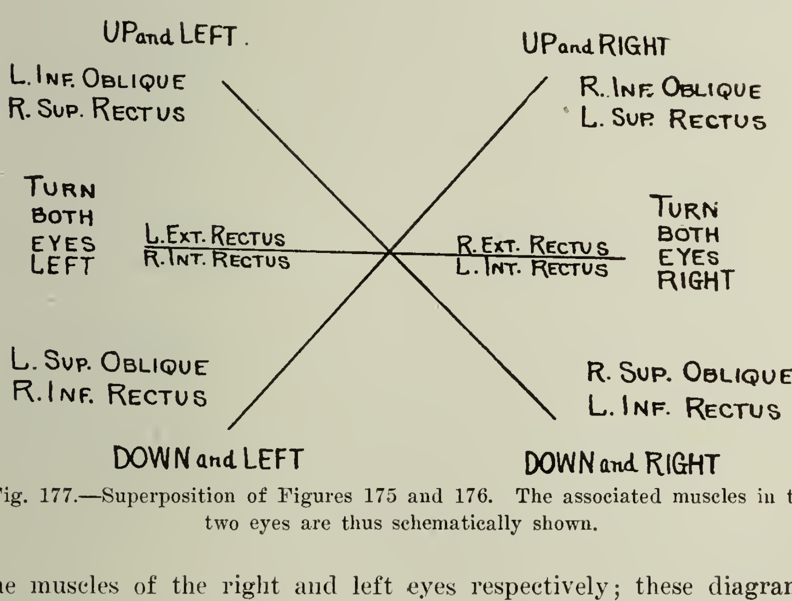


Fig. 177.—Superposition of Figures 175 and 176. The associated muscles in the two eyes are thus schematically shown.

the muscles of the right and left eyes respectively; these diagrams are based on the assumption that the eyes are in the primary position when the movement in the various directions begins. A superposition

of these two diagrams gives us Fig. 177 in which the associated muscles in the two eyes are shown. It will be seen at once, for example, that in the movement of both eyes directly to the right the muscles which predominate in this action are the right external rectus and the left internal rectus; in movements of the eyes up and to the right the two muscles principally concerned are the right inferior oblique and the left superior rectus, and so on through the six principal movements of the eyes. It follows, therefore, that the two eyes work together as one; as Hering says in introduction to his monograph on binocular vision, the two eyes may be regarded as halves of a single organ. It is impossible for one eye to move in one direction without the other paralleling its action in every particular when normally acting. A nervous impulse from the cortex must necessarily be divided between the two eyes. The number of conjugate innervations is at present unknown. Five have long been recognized: (1) binocular elevation, (2) binocular depression, (3) binocular dextroduction, (4) binocular lævoduction and (5) that for the totally distinct act of convergence. These five innervations are more or less under voluntary control. (See Hansell and Reber, *Ocular Muscles,* pages 26-31.)

347. To the above conjugate innervations Maddox adds the following: (1) binocular dextrotorsion and (2) binocular lævotorsion, the existence of which can be deduced from physiological experiments, phenomena of rotational nystagmus and changes in cylindrical corrections necessary when the head is sloped toward either shoulder; (3) binocular intorsion and (4) binocular extorsion for regulating the parallelism of the vertical meridians of the retinas with each other; (5) divergence, (6) one for raising the right visual axis above the left and (7) another for raising the left visual axis above the right.

348. Savage has given a most elaborate discussion of the conjugate innervations and their relations to muscular defects in his books on *Ophthalmic Myology* and *Neuro-myology.* According to this writer there are nine conjugate brain-centers all under the control of the will and each connected with two muscles, one belonging to each eye; there are twelve centers controlled by the fusion faculty of the brain, each center being connected with only a single muscle. These fusion centers exist in the interest of binocular single vision; these centers must act independently of and co-ordinately with the conjugate centers. To accomplish their work the twelve muscles belonging to the two eyes have *nine conjugate innervations:*—(1) the one to elevate both eyes, the two superior recti, (2) the one to depress both eyes, the two inferior recti, (3) the one to converge both eyes, the interni, (4) the one to move both eyes to the right, the right externus and the left

internus, (5) the one to move both eyes to the left, the left externus and the right internus, (6) the one to keep the vertical axes from diverging above, the two superior obliques, (7) the one to prevent their converging above, the two inferior obliques, (8) the one to maintain parallelism of the vertical axes and the median plane of the head when the point of view is obliquely up and to the right or down and to the left, or the right superior oblique and left inferior oblique and (9) the one to maintain parallelism of the vertical axes of the eyes and the median plane of the head when the point of view is obliquely up and to the left or down and to the right, thus involving the left superior oblique and the right inferior oblique. Hence the internal recti and the four obliques are each connected with two conjugate innervation centers, while the remaining muscles are each under the control of only one conjugate innervation center. There are in addition *twelve fusion brain-centers* not under the control of the will; when one of these basal centers discharges neuricity only a single muscle responds; when a conjugate center discharges neuricity both muscles of a pair respond (see Savage *Ophthalmic Neuro-myology* and the section on **Muscles, Ocular,** Volume X, of this *Encyclopedia*).

349. We may with propriety ask the question: By what mechanism can we explain the motor impulses which rotate both eyes in the same direction at the same time as we look from right to left or again in opposite directions as in convergence? Innumerable theories have been offered and discarded in turn as our knowledge of the functions of the cells in the nuclei and in different portions of the brain have grown more exact. The third, fourth and sixth pairs of cranial nerves and the carotid plexus of the sympathetic system innervate the muscles governing the movements of the eyeball, the accommodation and the iris. From these cortical centers are derived nerve fibers which run indirectly to the nuclei and undoubtedly have connections with other centers in the brain the functions of which are associated. The fibers have not been dissected or strictly outlined. Their presence must be assumed in order to explain mental processes, a portion of the evidence being the voluntary although not always conscious ocular movements. The nuclei have been studied and their locations, their relations to each other and their functions to a large extent determined. From the nuclei large numbers of nerve fibers are given off which unite to become distinct nerve trunks easily seen at the base of the brain and followed to their exit through the sphenoidal fissure to be distributed to their respective terminations in the muscular tissues. Russell's experiments led him to conclude that the cerebellar cortex plays no little part in the ocular movements and that it is associated with the

cerebrum in these functions. The areas which are supposed to preside over the different eye movements, according to Russell, and which are five in number, are above the center of the fissure of Sylvius just anterior to the large motor area.

350. The mass of cells composing the nucleus of the third nerve lies on both sides of the median line next to the corpora quadrigemina and under the aqueduct of Sylvius. The nucleus is from six to ten milli-

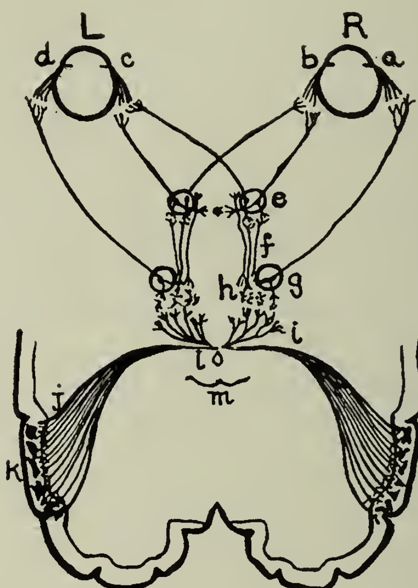


Fig. 178.—Bernheimer's Scheme to Illustrate the Action of the Associated Muscles in Lateral Movements and in Convergence.

a, Right external rectus; *b*, right internal rectus; *c*, left internal rectus; *d*, left external rectus; *e*, third nerve nucleus; *f*, communicating fibres; *g*, sixth nerve nucleus; *h*, fimbriated cells; *i*, arborizing ends of the fibres to the opposite side of the cerebral cortex; *k*, cortical centers; *l*, aqueduct of Sylvius; *m*, roof of the corpora quadrigemina. (Graefe-Saemisch *Handbuch*, second edition.)

meters in length and of varying breadth, mingling with adjacent cells. Posteriorly they encroach upon the cells of the fourth nucleus without a distinct demarcation between them. The mass may be divided into nucleoli, each with its separate function and muscle control. Fig. 178 gives Bernheimer's scheme to illustrate the action of the associated muscles in lateral movements (lateral conjugations) and in convergence. In the diagram the letters have the following significances: *a*, right externus rectus; *b*, right external rectus; *c*, left internal rectus; *d*, left external rectus; *e*, third nerve nucleus; *f*, com-

municating fibers; *g*, sixth nerve center; *h*, fimbriated cells; *i*, arborizing ends of the fibers to the opposite sides of the cerebral cortex; *k*, cortical centers; *l*, aqueduct of Sylvius; *m*, roof of the corpora quadrigemina. It will be seen that the fibers from some of the nuclei run directly to the muscles on the same side, while others are crossed to stimulate those on the other side, the crossing taking place chiefly in the anterior half of the nucleus. Strictly, the inner or median part of the nucleus belongs to the intraocular muscles and the outer part to the extraocular muscles. The anterior and principal part of the nuclear masses belongs to the third nerve.

351. Bernheimer conducted a large number of experiments on apes to determine the site of the centers for eye movements and reached the following conclusions:—(1) The gyrus angularis and especially its middle part of both hemispheres is the only cortical center for synergic eye movements. (2) The right gyrus angularis controls movements toward the left, up and left and down, while the left gyrus controls movements toward the right, up and right and down. (3) The anterior corpora quadrigemina are neither a reflex center for eye movements nor the passage for the neurons. (4) The connection-neurons between the nuclei and the cortex are all crossed in the angular gyrus in the median line under the plane of the aqueduct of Sylvius between it and the nuclei. (5) The end filaments of the connecting fibers communicate probably by other cells (*schalzellen*) with the roots of the motor ganglion cells of the nuclei. (6) The schalzellen lie probably imbedded and scattered in the central gray matter and form no cell mass. (7) Since there is a partial crossing of the third, the complete crossing of the fourth and the connection of all the oculomotor nuclei with each other, it may be asked whether the crossing connecting fibers of one angular gyrus equally influence the muscles of both eyes.

352. *Convergence.* When normally balanced motor muscles are at rest a single distant object can be fixed by the two eyes and the images, which fall upon the maculæ, are fused into a single mental impression. In the binocular single vision of a near object the eyes must be converged or turned toward each other so that the images may still be formed on the maculæ. Convergence is independent of and can be associated with any other motor muscular action, such as lateral rotation, elevation or depression of the eyes; in fact, depression is a usual accompaniment of convergence since reading, writing and other near work are generally done below the level of the eyes. Since convergence is an angular movement of the eyes effected around the centers of rotation it is measured in degrees: the farther the two

eyes are apart the greater must be the angular movement for fixation and *vice versa*. Hence for any given distance of the object viewed the actual convergence depends upon the interpupillary distance. It is common custom (although not correct) to disregard the interpupillary distance and to measure and express this function in meter-angles. The *meter-angle* is that angular displacement of the one visual axis from its primary position of parallelism when a point on the median line one meter from the eyes is fixed. It is, therefore, equal to the angle *c*, Fig. 179, between the median line *DF* and the visual axis *RF*.

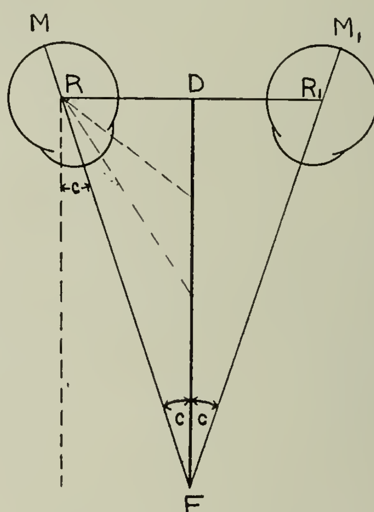


Fig. 179.—Illustrating Convergence and the Principles of the Calculation Trigonometrically of the Value of the Meter Angle.

The meter-angle is then that angle whose sine is half the interpupillary distance, i. e.,

$$\sin c = \frac{RD}{RF}.$$

Since the distance between the rotational centers of the eyes is considered fixed and the sines increase less rapidly than the angles, the angular value of two meter-angles is slightly more than twice the value of one meter-angle and so on.

353. The value of the meter-angle varies with the interpupillary distance. If the latter is 60 mms. the value of one meter-angle is 1° 45′. If the P. D. (interpupillary distance) is 64 mms. the M. A. (meter-angle) is 1° 50′. If we neglect the difference between sines

and tangents, the M. A. can be expressed in terms of the prism diopter, due to Prentice, as equal to half the P. D. in centimeters. Thus, if the P. D. is 64 mms., the M. A. equals 3.2△. In other words, a 3.2△ prism, base out, before each eye in the primary position will cause a convergence of 1 M. A. in order that binocular vision at infinity may be retained. Prentice gives the following simple rule: Read the patient's interpupillary distance in centimeters, when half of it will indicate the prism-dioptries required to substitute one meter-angle for each eye. This rule likewise enables us to quickly calculate the amount of convergence demanded for any intraocular distance with fixation at any specified points. For instance, if the interpupillary width is 70 mms., then 1 M. A. = 3.5△ and if such eyes are fixing a point at 33.3 cms. (equals 3 M. A.), each eye must converge 10.5△ or the total convergence demanded is 21△. The number of M. A. of convergence demanded at any point can be calculated from the relation that

$$\frac{100}{\text{Distance in cms.}} = \text{M. A. of convergence.}$$

This meter-angle system was invented by Javal and Nagel to measure the convergence in a manner analogous to the measurement in diopters which is used for refraction and accommodation.

354. The *range of convergence* is the actual distance between the near and the far points of convergence. It usually extends from infinity or (possibly) more often from a negative position to within a few inches of the eyes. The *range of convergence,* or the space over which convergence can be exerted is expressed by $r_c - p_c$ in linear measure. The near point of convergence is found by approaching a pencil or a card carrying a black vertical line or row of printed letters towards the eyes to the nearest point at which it is seen single, or by the use of an ophthalmoscopic lamp as advocated by Hansell and Reber, in which the observer watches the corneal reflections of the light as it is approached toward the eyes and in which failure of one or both eyes to fix is noted by the shift of position of the corneal image. The far point of convergence is found by using a Maddox rod or similar device before one eye and noting the position of rest and measuring its amount by prisms bases in or out; the position of rest may be one of parallelism, divergence or convergence. The *amplitude of convergence* is the total amount of convergence force that can be exerted and is, therefore, the distance between the punctum remotum and punctum proximum expressed in meter-angles or prism-diopters:

i. e., $A_c = P_c - R_c$. Age has a much less effect upon the amplitude of convergence than upon the amplitude of accommodation; it is stated by some writers and investigators that age has very little effect and this statement seems very likely correct. The *relative convergence* is the amount, either positive or negative, that can be exerted when the accommodation is fixed for a given distance. This *relative amplitude of convergence* is measured by the differenee between the strongest prisms, base in and base out, through whieh vision is single. These measurements are made preferably with the rotary prism, an instrument composed of two superimposed prisms of the same strength and operated by a speeial mechanism whieh allows them to be turned in opposite directions. This rotary prism is turned in such a manner as to throw the apices outward or bases inward while the observed party looks at a distant small luminous source; the strength of the prism is increased until the subject sees two images. We thus obtain the *abduction,* or the negative relative convergence: for normal eyes this is about 5 to 7 prism degrees. The positive relative convergence, or the *adduction,* can be found by turning the apiees of the prisms inward or bases out and increasing their strengths until diplopia results. Adduction is normally much stronger than adduction; it may easily reach 20° to 30° of prism power or even more. The difference between—in reality the arithmetical sum of—the two, i. e., the adduction and the abduetion, gives the *total relative amplitude of convergence,* the accommodation remaining passive if the eyes under test are emmetropie or else put in this condition due to the correction of refractive errors. It is worthy of note, in passing, that these determinations frequently vary amongst themselves because the observer does not attempt with equal effort to fuse at all times, because there is fatigue under repeated trials and also because the rotary or mobile prism and the insertion of and replacing of prisms one by one from the trial case apparently give different results. Furthermore, it should be pointed out that the amount of deviation or turning of the visual line in any case is approximately one-half of the prism value in degrees inserted before the eye. The deviation produeed by a prism corresponds exactly to half its angle if the index of refraction is 1.50. If one can overcome a prism of eight degrees, apex outwards, it is equivalent to saying that he can make the visual line diverge four degrees.

There are two general classes of convergence which demand differentiation, the so-called *static* and *dynamic* convergences. The term "*static*" is applied to convergence when the eyes are at rest and it may, therefore, be positive, negative or zero. "*Dynamic*" conver-

gence is always positive; it involves the muscular process by which the visual axes are so turned that the point of fixation may have an image on both maculæ.

355. Maddox divides convergence into three portions:—

(1) *Tonic* convergence, which is exerted in order to fix an object at infinity, i. e., to render the visual axes parallel. It may be positive, negative or nil according to the evidence furnished by the muscle balance tests at twenty or more feet.

(2) *Accommodative convergence.* This accompanies convergence and is always positive.

(3) *Fusional or supplementary* convergence, exerted in order to fuse the images.

The sum of these three causes the visual axes to meet at a near point so that single and simultaneous binocular vision results. In distant vision only the tonic or initial convergence is demanded. When accommodation is exerted it is always accompanied by convergence or conversely convergence is normally accompanied by accommodation. The two are simultaneously coexistent and so naturally associated that it is difficult for ordinary eyes to exert the one function without the other. It is commonly taken that for one diopter of accommodation one meter-angle of convergence is also normally exerted.

356. *Accommodation and convergence.* Because of a common or associated innervation or harmony of action there is an intimate connection between these two functions. If it be taken that neither comes into action for clear binocular vision at infinity, then for a near point or object both are equally required. At 50 cms., for example, 2 diopters of accommodation and 2 M. A. of convergence would be required. It is almost impossible to judge which is brought into action first or whether their action is simultaneous, but the weight of evidence is that fixation first occurs to be followed simultaneously by the accommodative act.

357. It has been taught by many that when the eyes are accommodated for any given distance the initial (tonic) and accommodative convergences then in force should be just that quantity required for fusion of the images and that there is normally no call for supplementary or fusional convergence. But if the initial and accommodative convergences are insufficient for the distance under test some positive fusional convergence must be exerted to obtain single vision, while if the sum of these two quantities exceeds the amount of convergence demanded then some negative supplementary convergence, or divergence, must be brought into play. Positive supplementary convergence may be demanded if the initial position is that of divergence or if less than one M. A. of convergence comes into operation with

each diopter of accommodation exerted. Negative fusional convergence may, in turn, be demanded because of the initial convergence or because more than one M. A. of convergence results with each diopter of accommodation. These statements must be, in their import, correct; the chief point upon which differences of opinion exist lies in the question of the accommodative convergence. If the accommodation and convergence are dissociated and investigations are carried out at the normal reading point, while the patient accommodates, by means of the insertion of a 4△ base up and down before each eye respectively, the patient viewing a line of type and subjoined arrow or if the Stevenson's muscle testing device is used, experimentation by such authorities as Maddox, Howe and Worth has led to the conclusion that there is a normal or physiologic exophoria at 12 to 13 inches of approximately 4°. It does not appear valid, therefore, to attribute the whole of the innervation necessary to binocular vision at a near point to the tonic and accommodative convergences only but rather to the tonic, accommodative and fusional convergences. If the hypothesis of physiologic exophoria is correct we should *not* then expect to find orthophoric conditions at distant and near points (as indicated by such tests as the Maddox rod or von Graefe's dissociation test) to be in agreement in any case. We should have such a status of affairs as the following:—at 20 feet no vertical or horizontal imbalances; at 13 inches some 4 to 6△ base *in* to bring the images into a line with each other or 6△ of exophoria at near. If such a basis is assumed to indicate orthophoria for distance and near it must follow that there is an association of convergence with accommodation but that there is not the usually stated 3 to 1 ratio between these two functions *per se* but a lesser ratio of approximately 2 to 1, the remaining portion of the convergence demand being met by the fusional convergence and ultimately, therefore, giving a relation such as that commonly stated of 1 M. A. of convergence to 1 diopter of accommodation. An emmetropic pair of eyes evidencing orthophoria at infinity (20 feet) would, therefore, possess binocular single vision at near points through the functions of both accommodative and fusion convergences. This topic is discussed in detail by Sheard in his volume on *Dynamic Ocular Tests.* (Note:—Simple calculation by the Prentice rule or by trigonometry shows that approximately 18△ to 20△ of convergence is demanded when a pair of eyes, about 64 millimeters from center to center, fix a point at 13 inches.)

358. While the accommodation and convergence are thus intimately related and normally co-existent, yet the one can be made to exceed the other. For at any given distance we can reduce accommodation with

convex lenses and increase its operation with concave lenses without producing double vision, thus proving that convergence does not conform to the altered accommodation. With prisms base *in* we can decrease and with prisms base *out* we can increase the convergence without disturbing the clearness of vision. This disturbance to clear vision, it is commonly stated, would occur if accommodation was proportional to convergence. The whole of these phenomena are fairly readily and logically explained if due regard is paid to fusional convergence as associated with, but entirely separated from, the accommodative convergence.

359. And again, since there is normally such intimate correlation between these actions of accommodation and convergence, it might appear possible that one single innervation would serve the purpose of

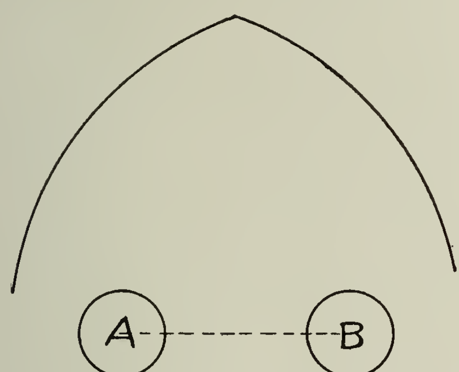


Fig. 180.—Line of Equal Accommodation. (After Maddox.)

the two. Maddox has raised this query and discussed it from geometrical and clinical viewpoints. Whenever the eyes are turned to the right or the left a differing proportion between convergence and accommodation is needed: for slight lateral movements of the eyes accommodation needs to be relatively increased but as soon as the motion exceeds a certain limit, the demand is reversed and the greatest demand is for convergence. In Fig. 180 we have a representation of the line of equal accommodation for near vision. It is made up of two curves: if an object is placed at any point thereof accommodation remains the same. It is composed of two arcs of equal radius described from the centers of their opposite eyes. It is assumed that the centers of accommodation are so intimately connected that one eye does not normally accommodate more than the other when looking at any point outside of the median plane. Since accommodation with normal refraction implies positive effort, the eye which is farthest

from the object and can see it with least effort determines the accommodation for both.

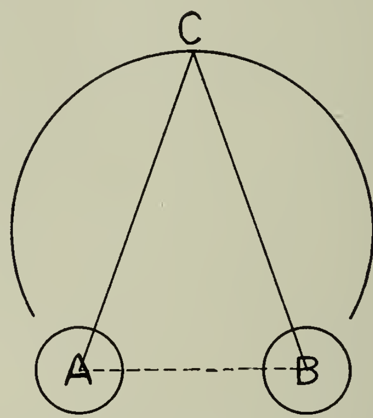


Fig. 181.—Line of Equal Convergence. (After Maddox.)

360. The equal-convergence curve in Fig. 181 is a portion of a curve which passes through the centers of rotation of the two eyes and possesses these attributes:—

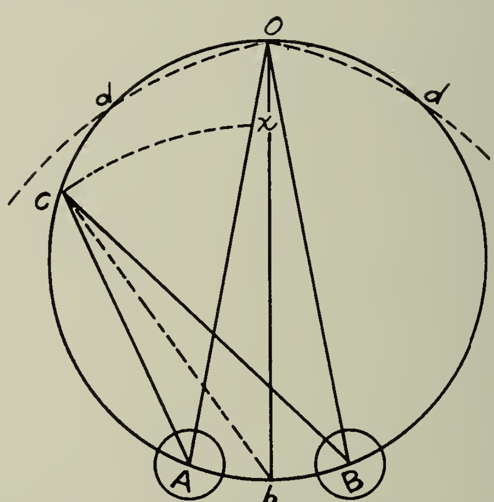


Fig. 182.—To Illustrate the Relation Between Convergence and Accommodation in Lateral Fixation. (After Maddox.)

(1) The angle of convergence is the same whatever point in it is made the point of binocular fixation.

(2) In glancing from any one point in it to any other, both visual

axes traverse equal angles. Thus in Fig. 182 the angles *OBc* and *OAc* are equal. In contrast to this we have the condition in which the eyes fix a point in a plane surface, such as a wall, when the point of regard is shifted to the right or to the left. If the point of fixation is to the left of the median plane the left axis passes through a greater angle than the right.

(3) The line which bisects the angle of convergence is the one to which, hypothetically, objects upon the maculæ should be mentally referred. This line is represented as *cb* in Fig. 182. It is inclined to the median plane by an angle which measures the obliquity of vision: it is equal to the angle through which each visual axis has turned in shifting the fixation from the median plane point *O* to any other point in the circle of equi-convergence.

361. If the two curves of Figs. 180 and 181 are applied to each other as in Fig. 182, the dotted arcs indicating the line of equal accommodation, we see demonstrated the fact that within a certain degree of obliquity of vision the proportion of convergence to accommodation is greater than in the median plane, while for increased obliquity the proportion is less. At the points *d,d* the relation between accommodation and convergence is the same as at *O*. The distance of *d* from *O* is equal to the inter-central distance, *AB*, of the observer. This diagram also shows how the accommodation and convergence required in looking at any point obliquely may be compared with those needed in the median plane. In the case of any given point, *O*, we need only to describe a circle through it and the centers of rotation of the eyes, and from the center of the farthest eye to draw the arc *cx* from *c* to the median line. The arc is then part of the line of equal accommodation. In binocular vision at the point *c*, therefore, convergence must act as if for *O* and accommodation as if for *x*. Were the relation between accommodation and convergence inflexibly that, for instance, demanded for objects in the median line there would be a diplopia for any object outside of this median plane except possibly at one point on each side within which diplopia would be heteronymous from relative divergence and without which it would be homonymous from relative convergence. Furthermore, the farther the point of fixation is moved from the median plane the greater becomes the physiological difficulty of converging the eyes so that the excess of convergence effort required above the demands made upon the accommodative efforts increases in proportion to the lateral deviation of the line of regard. Bolton found the following deficiencies in

convergence with accommodation for 10 inches at the various angles indicated. (See Maddox, *Ocular Muscles.*)

For an Object Distant	Exophoria
On looking straight forward (median plane).....	— 6°
Looking 10° to the right........................	— 7° 10′
Looking 20° to the right........................	— 8° 54′
Looking 30° to the right........................	—10° 45′
Looking 35° to the right........................	—12° 36′

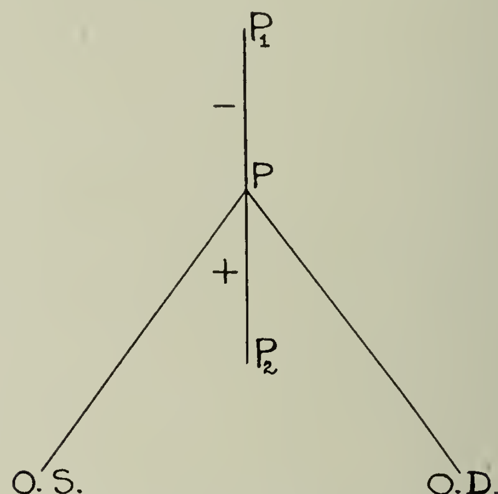


Fig. 183.—Illustrating Relative Accommodation.

The last figures show the visual axes to be actually divergent so that if they were prolonged they would meet at a point behind the head. "It is," says Maddox, "just as much as we can do to overcome this tendency to diplopia in the lateral limits of the field of fixation."

362. *Relation of accommodation to convergence—Relative accommodation.* The amount of accommodation which it is possible for an individual to exert or relax with respect to a given degree of convergence is called the *relative accommodation.*

Suppose that the eyes are accommodated and also converged to a point *P*. Then if concave glasses of gradually increasing strength are placed before the eyes, the patient will retain the same degree of convergence but will be forced to increase his accommodation up to a certain limit. This degree will be represented by the strongest con-

cave lenses which can be overcome and is equivalent to accommodation at a point nearer than that to which the eyes are converged, as for example, P_2 in Fig. 183. The distance PP_2 will then represent the *positive* portion of the relative accommodation. In a similar manner, if the person continues to converge to the point P and convex lenses of gradually increasing strength are placed before the eyes, there will be relaxation up to a certain point or limit, for example, P_1. The distance PP_1 will then represent the *negative* part of the relative accommodation; hence the total range of relative accommodation will be equal to the sum of the positive and negative portions. A simple illustration will not be inappropriate; the reader is referred for further information to the writings of Donders and to the more recent and excellent treatises of Howe on *The Muscles of the Eye*. Assuming an emmetropic condition, we find the positive part of the relative accommodation by inserting before the patient's eye the strongest concave lens which does not blur the line which should be seen at that distance: these lenses represent approximately the degree of extra accommodation made by the ciliary muscles. Let us suppose that they are — 3.25 D. S. Since this represents the apparent rather than the real amount of accommodation exerted, the real amount must be calculated. If this lens is placed about 30 mms. from the nodal point of the crystalline lens, then

$$\frac{1}{R_1 - 0.03} - 3.25 = 0$$

or the real value, R_1, of the positive accommodation is 2.95 diopters. The negative portion of the relative accommodation should next be measured by using convex lenses; inasmuch as we have assumed emmetropia we have an actual negative accommodation of zero value however.

363. Let us next take convergence at one meter. In this case the patient fixes test-letters properly constructed for the distance at which they are to be used as in Howe's optometer. Care must be exercised that the pupillary distance of the frames carrying the lenses is changed so that the optical centers of any lenses which may be inserted are in the lines of the visual axes when the individual under examination is viewing the test-type at the distance specified. An emmetrope at one meter's distance exerts naturally an accommodation of one diopter. We then find the strongest concave glasses that can be overcome in the manner previously described. Suppose this to be — 3.00 D. S. The actual amount of positive relative accommodation can be shown

to be about 2.6 diopters, since calculation (see footnote) indicates that the total accommodation is 3.6 diopters of which the emmetropic eye without a lens, converging at one meter, will exert one diopter. The negative part of the relative accommodation with 1 M. A. of converg-

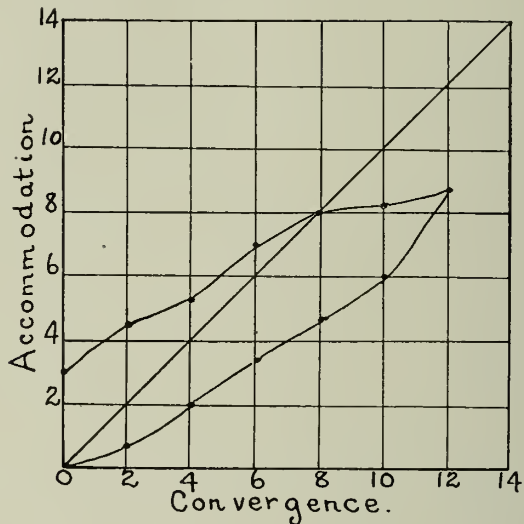


Fig. 184.—Lines Showing the Relative Accommodation as Plotted in a Given Case. (Howe's *Muscles of the Eye.*)

ence must next be obtained. This is done by the employment of convex lenses until the type normally readable at the distance under which the tests are made begins to be blurred. Suppose this is + 0.75 D. S. The total range of the relative accommodation at one meter is,

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Let P represent the distance from the nodal point of the eye to the point p and P_1 the distance from the nodal point to the point p_1 and let d be the distance of the lens from the nodal point. In these formulae p represents the point looked at while p_1 is the point for which the eye is adjusted. Then if a *convex* lens is placed before the eye, its dioptric value, $\frac{1}{F}$, is correctly determined from the equation

$$\frac{1}{F} = \frac{1}{P - d} - \frac{1}{P_1 - d}$$

$$\text{or} \quad \frac{1}{P - d} = \frac{1}{P_1 - d} + \frac{1}{F}$$

When a *concave* lens is placed before an eye the formula becomes

$$\frac{1}{P - d} = \frac{1}{P_1 - d} - \frac{1}{F}$$

P_1 is, of course, the term whose value is sought in these experiments upon the relative accommodation.

therefore, 3.32 diopters. Similar measurements on the negative and positive portions of the relative accommodation should then be made with convergences of two, three and four meter-angles and so forth. In Fig. 184 there is plotted a set of curves showing the relation between the positive and negative portions of the relative accommodation and convergence. The diagonal running across from the lower left-hand to the upper right-hand corner represents the relation which would exist if there was found to be one meter-angle of convergence associated with each diopter of accommodation. Hence the positive part of the relative accommodation is recorded above the diagonal and the negative part below it: the accommodation values are usually plotted vertically and the convergences horizontally. In Fig. 184, for example, with fixation at infinity in a specified case of emmetropia, the positive relative accommodation is plotted as 3 diopters while the negative relative accommodation is zero. Passing on to 1 M. A. of convergence, we proceed to plot our positive and negative relative accommodations from the diagonal line at the point opposite 1 diopter of accommodation and 1 M. A. of convergence and not from the horizontal axis. In the figure as plotted we see that the positive relative convergence is equal to $3.5 - 1 = 2.5$ diopters and the negative accommodation to $1 - 0.25 = 0.75$ diopter, and so on. When there is no longer any positive portion of the relative accommodation the curve crosses the diagonal. Beyond this point there is only a range in the negative portion of the relative accommodation.

364. If the patient is ametropic the statement that at a distance of one meter there is exerted one diopter of accommodation does not hold. Thus, in cases of myopia, convergence occurs while accommodation is impossible: in a case of myopia of 4 diopters there will be a convergence of six meter-angles but an accommodation of two diopters only. In hyperopia more accommodative than convergence effort is required: a hyperope of 3 diopters will exert 5 diopters of accommodation when using 2 M. A. of convergence. These facts must be taken into account in the plotting of accommodation—convergence curves. This is done by starting the diagonal either above or below the zero mark taken for emmetropia.

And again, the *negative* part of the relative accommodation for any point of convergence may be found objectively by the methods of *dynamic skiametry.* The mechanical arrangement necessary for such tests consists simply in the attachment of a small card, carrying printed characters, to the side of the retinoscope. Observation and fixation points are then one and the same. To insure the presence of both convergence and accommodation the subject under test is required to read

or decipher (i. e. to at least make the effort) the material on the fixation card. The operator proceeds to add plus lenses binocularly, viewing the reflexes in each eye in turn, until *reversal* of shadow is obtained. This gives the total lens quantity demanded, from which there must be algebraically deducted the static corrections found if we are desirous of knowing the true relative negative accommodation when the eyes have been optically re-established as nearly perfect as seems possible. Such tests can, of course, be made at any fixation points desired. Furthermore, such tests as made by dynamic skiametry in which such additional lens quantities are added as will afford neutrality of shadows at the point fixed, often furnish valuable information as to the optical assistance needed in order to adequately supply accommodative demands, correlate and harmonize economically accommodation and convergence or furnish an objective method of determining the proper reading correction in presbyopia. (See *Dynamic Skiametry* by A. J. Cross and *Dynamic Ocular Tests* by C. Sheard.)

365. The importance of such investigations may be questioned by the reader. Donders laid down the very important principle that "The accommodation can be maintained only for a distance at which, in reference to the negative part, the positive part of the relative range of the accommodation is tolerably great." Howe says:—"It is desirable to determine whether the action of that (ciliary) muscle is normal or excessive or insufficient. At least a general idea as to the power of the ciliary muscle is shown, as already stated, simply by placing a minus three (diopter) glass before each eye and asking the patient to read again the distant test-type. I have learned to regard this as *one of our most important tests.*"

366. *Relation of accommodation to convergence—Relative convergence.* The procedure for measuring relative convergence is similar to that for measuring the relative accommodation. It is very similar in theory also. With a given accommodation, then, the strongest adductive (bases out) prisms show the relative near point of fusion while the strongest abductive prisms show the relative far point of fusion. If a person whose ocular base line is 58 mms. can, when fixing the test object at 6 meters, overcome adducting prisms amounting to 14 degrees, we can calculate (or take from tables already worked out) the amount of this positive relative convergence as 2.2 M. A. The same method is followed in obtaining convergence powers at other fixation points.

367. Fig. 185 gives curves showing the positive and negative portions of the relative convergence. It is plotted in the same manner as an accommodation-convergence curve, except that, instead of reckon-

ing vertically from a certain point of the diagonal, we count horizontally from that same point of the diagonal. So many squares to the right show the positive part of the relative convergence and so many squares to the left show the negative part. We find that the lines representing positive and negative convergences are often almost parallel to the diagonal in the system of co-ordinates employed. To plot the relative convergence with parallel axes we should represent the positive part on the right of the first horizontal line, i. e., about two squares from the zero point in the illustrative case taken in the preceding paragraph, whereas the negative portion would be represented on a continuation of that line to the left by a distance of 1.8

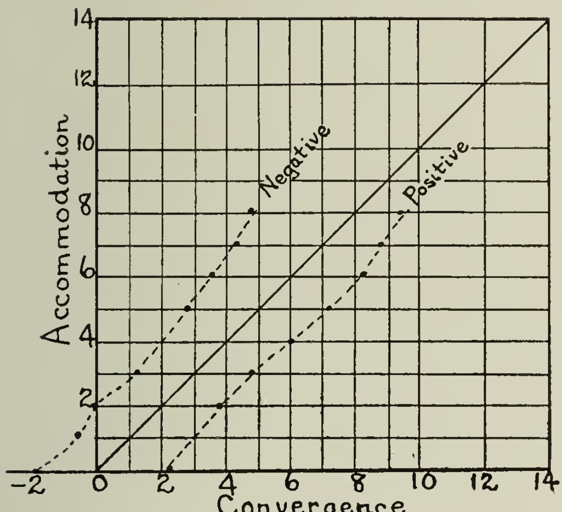


Fig. 185.—Lines Showing the Relative Convergence as Plotted in a Given Case.

squares. With one diopter of accommodation the positive part of the convergence would be at a distance of two squares from the right of the diagonal and the negative portion at a distance of 1.8 squares to the left of the diagonal; these figures are assumed to have been clinically found in a particular case. The remaining points of the positive and negative relative convergence curves are then determined in a similar manner for different amounts of accommodation demanded.

XX. THE PROJECTION OF VISUAL IMPRESSIONS

368. *The general law of projection.* An impression at any point of the retina is projected outward into the visual field following the line of direction. This line of direction is one which passes through

the retinal point involved and the nodal point of the eye. It is important to recognize that projection is not a faculty of the retina but is a mental act. The more perfectly the projection is performed the more nearly do the projected images or pictures of external objects coincide with the objects themselves. Projection is a congenital faculty but is perfected during the exercises of childhood when the real position of objects is constantly being discovered by other senses. Conversely it may be said that an exterior point upon which the eye is focused has its image formed at the point of intersection of the line of direction with the retina. When referring, therefore, to objects seen distinctly the law of projection is equivalent to saying that we see objects in the direction in which they really are. Since the image of an external object formed upon the retina is perverted and inverted it follows that a ray proceeding from the temporal side of an object will meet the retina at the nasal side and a ray proceeding from the upper portion of the object will meet the retina in its infra or lower portion, the macula being regarded as the visual center of the retina, and so on. It follows that the field of projection is re-inverted so that its right half corresponds to the left half of the retina and its upper half to the lower half of the retina. The law of projections applies not only to the ordinary phenomena of vision but also to all the retinal impressions, the phosphenes, after-images, entoptic phenomena and circles of diffusion. The deformities of objects seen indirectly, which appear to show that this law is not followed very exactly for very peripheral parts of the retina, may be cited as exceptions.

In order to be able to form a correct idea of the position of an exterior object it is necessary that we know its direction and its distance. Judgment of direction is formed better monocularly than binocularly: the superiority of binocular vision is apparent in the judgment of distance.

369. *Projection of the visual field.* The law of projection regulates the manner in which objects are localized in the visual field but does not regulate the projection of the visual field in its entirety. The latter depends upon the manner in which one judges of the position of his own eye or the direction of the visual line. One of the most important factors in regard to the judgment of form, size and direction of objects is that these judgments are largely based upon what is known as the *muscular sense.* Helmholtz says that there should be distinguished under the term "muscular consciousness" a number of sensations essentially different. They are: (1) the intensity of the effort of the will by which we endeavor to cause the muscles to act, (2) the tension of the muscles, i. e., the force by which these muscles

strive to act, and (3) the result of the effort which is indicated externally by an effective shortening of the muscle. To these Stevens would add a fourth which he calls "the consciousness of the intensity of the will effort to accomplish the muscular change": in other words, an element of the muscular sense is the knowledge gained by experience of the individual, or inherited from the experience of others, of the intensity of the will impulse demanded for the execution of a muscular act. We are, for example, fixing a point *A* and desire to fix another point *B*. As long as *A* is fixed, *B* is seen by indirect vision and the distance between the images permits us to judge of the amount of innervation required to bring the line of regard to *B*. Generally and normally this judgment is quite exact and instantaneous so that we bring the look toward *B* almost without hesitation. Due to the innervation there results a contraction of the muscles, a change in the position of the eye and a change of the position of the retinal image until the image of *B* is formed on the fovea. As Tscherning remarks, it might appear plausible that the sensation of the more or less considerable contraction of the muscles, the gliding of the eyes between the lids and other correlated phenomena should furnish us with information on the direction of the visual line, but this is not true. This direction is judged solely by the degree of innervation which has been used to bring the line of regard into this direction. Observations of patients affected with ocular paralysis establish this statement. If, for illustration, a patient is affected with paralysis of the right external rectus and he is told to close his left eye and to look to the right, he may supply the necessary innervation. But the eye remains practically motionless on account of the paralysis while the patient, on the other hand, believes that he has moved his eye to the right so that there results a false projection; if the patient under observation is told to move his finger rapidly towards an abject situated to the right, not having sufficient time to guide himself by the sight of his finger, he consistently moves it too far to the right. A person with normal ocular innervations and muscular responses can perform this experiment satisfactorily by looking to one side while a traction is exerted in the opposite direction on a fold of the skin near the external canthus. This traction is communicated by the conjunctiva to the eyeball. Because of the resistance thus offered one is obliged to use a stronger innervation to bring the "visual regard" to the opposite side; from this it may be concluded that the look is carried farther in this direction than it actually is and this causes projection of the visual field in a false manner. The judgment of the degree of innervation demanded and used is quite exact because it is always corrected

by the results obtained. Suppose one places a ten-degree prism, base out before one eye and base in before the other, and then looks directly in front. As seen through the prisms an object situated at ten degrees to the right appears five degrees from the visual line and an innervation corresponding to five degrees only is demanded in order to fix it. One believes, therefore, that it is situated at five degrees to the right and if one desires to grasp the object the hand is not brought far enough to the right. A few repetitions of this experiment, however, suffice to remove the deception: one can learn very quickly how to allow for and reckon with prisms. When the direction of the visual line is correctly judged there is in monocular vision no possible illusion as to the direction in which objects lie. In monocular vision the center of co-ordinates is represented by the nodal point of the eye and the law of projections gives the direction of any radius vector. The position of any point in space is determined by the direction and length of the radius vector from the center of co-ordinates to the point in question: uniocular vision gives the direction but the length of the radius vector is lacking.

370. *Projection in binocular vision. Physiologic binocular diplopia.* The two laws—the law of external projection and the law of direction—are two of the most fundamental principles underlying vision. What has been said thus far treats only of monocular vision. Most individuals possess two eyes which act as practically equal visual machines: these are not, however, to be considered as mere duplicates one of the other or that, if one is lost, the other is still left. On the contrary, the two ordinarily act together as one instrument and there are many visual phenomena and many judgments based upon these phenomena which result entirely from the use of two eyes as one instrument. The phenomena of binocular vision are less physical and more psychical than those of monocular vision. They are more obscure, illusory and much more difficult to analyze since they are more subjective and more closely allied to psychical phenomena. When the two eyes perform their functions correctly both of them fix the same object; hence the *impressions of the two maculæ are projected to the same place.* Images formed upon the two foveæ are projected under all conditions to the same spot in space. In recent paralytic squint two candles held in line with the two visual axes appear as one. If a sheet of paper be punched with two small holes separated by the interocular distance and this is held up close to the eyes so that distant objects can be seen through them the two holes will be seen as one and will lie in the median line. And again, a bright point of light may be fixed with one eye so as to produce a small foveal after-image.

It will then be found that no matter what object is fixed with the other eye, or however much the eye having the after-image be displaced or made to squint, the after-image will be seen at whatever point is fixed by the other eye.

371. When a pair of eyes is in the primary position (i. e., looking straight ahead into distance) the fields of vision of the two eyes overlap except in a sector of about thirty degrees toward the temporal periphery of each field. A normal-sighted person, therefore, sees objects with both eyes simultaneously, the exception being for objects which lie on the extreme right or left which are seen with one eye only. When a distant object is under regard the two eyes assume such a position that a picture of the object is formed simultaneously on the central part of each retina. All other distant objects are focussed on functionally corresponding points of the retina. These impressions are then blended in the brain and one is conscious of only one picture. But binocular vision of near objects is a much more complex act inasmuch as it is necessary that there be ultimately blended images which do not fall, as we have previously discussed, upon corresponding points of the retinæ. In every ordinary act of vision, then, a large number of objects do not have their images formed on corresponding points of the two retinæ. For every position of the point of fixation there is an *horopter* in which all objects are seen single, while all other objects are seen double if close analysis is made. We have, then, the phenomena of *physiologic binocular diplopia*. The following is a simple but practical illustration. If two fingers are held before the face in the median line or plane, one being somewhat in advance of the other, and the nearer finger is fixed, two images of the more remote finger will then appear. The right image will disappear on closing the right eye and the left on closing the left eye, which shows that the *distal* diplopia, as Maddox calls it, is *homonymous* or uncrossed diplopia. If, on the other hand, the more remote of the two fingers is fixed, the nearer one will be seen double, the left image corresponding to the right eye and the right image to the left eye. The *proximal* diplopia is then crossed. These experiments teach us that objects nearer than the point of fixation and the horopteric surface connected with it have crossed images while all objects beyond the point fixed have homonymous images. This physiologic diplopia must, therefore, be constantly present yet no one is ordinarily conscious of seeing double.

372. It is evident, then, that when an object is seen double there is at least one of the images which does not coincide with the object. When one eye is closed the corresponding image disappears while

the other image does not change position. The information which the eyes under these conditions furnish us gives rise to a false interpretation; a false judgment must, therefore, persist at least for one of the eyes. The sight of normal persons is not necessarily similar to that arising in monocular vision. Physiologic diplopia is due to the fact that the different positions of the two eyes are not taken into consideration. One cannot, without a special investigation, tell whether an image belongs to one eye or the other. Every visual impression, from whichever eye it may come, is referred to a common and single center. In projecting the retinal fields into space the mind must have some "point or origin" or "line of direction." Reference has already been made in a preceding paragraph to the fact that the nodal point of the eye is the so-called center of co-ordinates in monocular projection. If, then, we take into account the different positions of the two eyes we shall have two centers of co-ordinates and the notion of the direction of an object would suffice to fully determine its position. The line of reasoning would then be somewhat as follows:—Since, when we fix a remote object A and see two images of a nearer object B, we see with the right eye only the object B to the left of A and with the left eye the same object to the right of A, the object must then lie in the middle plane and nearer than A; the object B would then be seen single and in its correct position. Instead of this, however, the impressions are referred as in monocular vision to a *single* center and we are informed that the object must be double since it is seen at once to the right and to the left of the fixed object. Hering places "this origin of co-ordinates" for binocular vision at a point midway between the two eyes exactly as if they were united into one *cyclopic eye*. This is, without doubt, the true type of binocular vision in which neither of the eyes plays a dominating or directing part. Some, however, and possibly the majority even of those who have equal visual acuity in the two eyes, apparently use one eye chiefly as the auxiliary to its mate rather than as an equal in the processes of projection. Under these conditions one eye is called the "directing eye" and the origin of projections appears to coincide with the origin of co-ordinates of this directing eye. Tscherning gives some experimental proofs to show that the center of projections in his own case coincides with his right eye. In fact it is commonly found in the physiologic diplopia of persons who are right-handed that the image which belongs to the right eye is more "substantial-looking" than the other. Tscherning describes the following simple experiment and draws from it a rather interesting conclusion as to the inferiority of binocular vision with its origin of projections midway between the eyes. He says: "We

fix binocularly an object placed at some distance in the median plane and we try, by quick experiment, to place a stick quite near the face in the direction in which we see the object: it is better to conceal the movement of the hand with a screen. Making this experiment I bring the stick pretty exactly on the visual line of the right eye. * * * Most persons examined show a tendency to prefer one eye or the other, which seems to indicate a tendency to a development of a uniocular vision in addition to the binocular vision like that which I have described for my eyes. Persons enjoying pure binocular vision must place the stick in the median plane; as the center of projection does not coincide with either of the eyes, these people cannot project correctly objects seen indirectly. This type of vision, therefore, seems inferior to the other as far as orientation is concerned.''

373. Since some exterior objects are seen double and some single, depending upon whether they lie within or without the horopteric circle on the one hand or upon it on the other hand, one might think that there would thereby result considerable confusion. But there is not: most persons have never observed double physiologic images before making the experiments involving this phenomenon. Under ordinary circumstances one's *attention* is brought to bear upon the object fixed and, furthermore, the gaze never remains for any length of time on the same object so that there is little time in which to observe double images. We know also that objects not fixed form their images on the peripheral parts of the retina where the sensitiveness and resultant perception are less distinct than at the macula. It is scarcely possible to suppose a serviceable binocular vision if the entire retina had an acuity equal to that of the fovea (Tscherning). Why this physiologic diplopia, which must be constantly present, does not ordinarily make one conscious of seeing double has been explained in two distinct ways which we may, for brevity, designate as (1) *the elasticity of the fusion faculty theory* and (2) *the image suppression theory.* This customary freedom from diplopia is possible, says Worth, not by the mental suppression of one of the images but by the marvellous elasticity of the fusion faculty. Both sets of impressions are received by the brain and by their combination assist in the perception and appreciation of depth. Some such view is evidently held by Stevens, who believes that the images of those points or objects which are seen doubly are not mentally suppressed but that they constitute an important, if not essential, part of the physical impressions which unite to constitute the basis for a complete mental conception of the field of view, and that the beauty of perspective and the harmony of objects in the field of view would be absent although

the skeleton of the field of regard might remain. Stevens cites in support of these statements the experiences of persons subject to gradual atrophy of the optic nerve, for when the field of view is much reduced they are unable to see their way to walk though they may read letters directly in front of them at the standard distances. "The images which fall upon spatially non-corresponding points therefore serve an essential purpose. They serve as finders in the field of space. By means of these peripheral images not only are the eyes enabled to turn from one object to another and from one part of the same object to another part, but there is a mental estimate of their relative positions on the retinas from which conclusions respecting the positions of objects in space are drawn. * * * What has been said of single images when the impressions are located at corresponding points and of double images when they are located at non-corresponding points is, then, in an important sense, a physical law, but there are circumstances which indicate that a higher law governs all these phenomena. It is the law of *unconscious conclusions.*"

374. We now turn to briefly discuss the *suppression* theory. As has been previously remarked, it is commonly found that in the physiological diplopia of persons who are right-handed the image which belongs to the right eye is more "substantial-looking" than the other. While attention is, then, diverted from the diplopia and concentrated upon the point of fixation, the less substantial image of objects outside of the horopter is in most persons so entirely ignored by the mind as to be "suppressed." Tscherning writes:—"It seems that this suppression of the images of one eye plays a great part in binocular vision and that it is this which generally causes us not to observe double physiologic images. It is not easy to know which of the two images is suppressed, for as soon as we pay attention to this question both appear. Generally it is the more eccentric image, or, in other cases, the image which, on account of the perspective, occupies the smallest retinal surface (Javal) which disappears. But in most persons there seems to be developed a certain superiority of the eye which is most frequently used separately and then it is always the image of the other eye which is suppressed."

375. *The horopter—The isogonal circle.* No subject in physiologic optics is so replete with conflicting views of different investigators and none shrouded in a greater mystery or confusion of contradictory ideas than that of the *horopter*. Helmholtz devoted considerable space in his *Handbuch* to the experimental and mathematical developments of the horopter: he worked out a single horopter of the infinite number which may exist and even that one, it is claimed by many, is

faulty because it is based on false premises. Some have, in the language of Giraud-Teulon, characterized the horopter as a "transcendental fancy": "when," he says, "all the labor of determining the surface curve (fulfilling the geodescial condition of the horopter) was ended it was found that this surface assumed the form of a torus. * * * It was not noticed that a table with four legs, a chair placed before us, was seen singly, although they certainly had not the attributes of a torus."

376. The *horopter* may be defined as consisting collectively of all the points in space whose images, with a given alignment of the eyes, fall upon corresponding points of the retinæ. All points outside of the point fixed are not seen double as in the case of physiologic diplopia in which the second object is inside or outside of the point fixed. If we fix a point A, for example, then a point C some ten degrees to the right or left of A is seen as well with the right eye as with the left eye: it is therefore always normally seen single. The entirety of the points seen single when a given point is fixed is the horopter. The definition of the horopter is apparently the only point upon which various investigators agree. By some it has been described as a line, by others as a surface and by Helmholtz as a complex combination of curves, planes and straight lines. "In a single case only," says Helmholtz, "is the horopter a surface; it is when the point of regard is situated in the horizontal and median planes and at infinite distance. The plane of the horopter is then parallel to the plane of regard. In the case of normal eyes thus directed toward the horizon the horopter coincides approximately with the ground on which the observer walks." This has been objected to somewhat strenuously by Stevens who believes that if it were correct much ocular inconvenience would result and that "according to this proposition, if the eyes should be directed to the ground at a few feet in advance of the pedestrian he would bring his horopter beneath the soil and all the objects on his pathway would appear, so far as an horopter is concerned, confused and indistinct."

377. Two fundamental concepts or tenets constitute the essential foundation for the doctrine of the horopter. They are: (1) the theory of the position and direction of the meridians of the retinas and the law which regulates the position of the eyes (law of Listing), and (2) the theory of corresponding points. In respect to both these principles there is considerable diversity of opinion. Helmholtz, Volkmann, Hering and others came to the conclusion that the horizontal meridians were all parallel with the external horizon but that the vertical meridians were only apparently vertical and that they

leaned out above and approached each other below. That Helmholtz included in his mathematical calculations his own individual defects, which he assumed were physiological features common to all, is the claim of those investigators who hold that the actual and proper position for a vertical meridian is the vertical position. And, again, as previously pointed out, there is no universal agreement upon the notion of corresponding points. For, to quote from Helmholtz, "Corresponding points in the two visual fields are those which are at equal distances and equal in direction from the corresponding horizontal and *apparently* vertical meridians." Stevens sums up his conclusions respecting this subject in the following statement:—"Corresponding points are those points in the retinas which answer to *proportional degrees of rotation* and which, for given points in the plane of the point of fixation, receive incident rays which must pass through the nodal points." They represent, on this view, the relation between the muscular and the retinal senses. It is, then, but little wonder that the horopter and its calculation and significance appear so confused in the literature, for various investigators have not been able to agree upon the status and interpretation of the two fundamental tenets underlying the horopter.

378. Assuming the viewpoint of Stevens, we may say that when the point of fixation is at infinite distance and in the median plane all horizontal meridians are horizontal and all vertical meridians are vertical: so again, if in the plane of the horizon the point of fixation is brought nearer, the meridians maintain their original relations and these relations will continue if the eyes are directed upward or downward, provided the visual lines remain parallel. If the point of fixation is such as to demand convergence of the lines of regard and if it is above or below the horizon, the head being in the primary position, then all horizontal and all vertical lines assume new directions; these torsional rotations are governed by the law of Listing. If the visual lines of the eyes converge and the plane of regard is depressed, the horizontal meridians of each eye will tilt downward toward the temporal side and upward toward the medial side; the vertical meridians will also tilt with the upper part outward and the lower part inward, the tilting being proportional to the depression and the lateral direction of the line of regard. Under these premises, three simple horopters can be found. First: the observer directs the gaze towards the horizon in the median plane at infinite distance, the head being in the primary position; the horopter will be a plane surface at right angles to the plane of regard. Second: if the gaze is directed downward and to a few feet in advance, the horopter will be very

nearly at right angles to the plane of regard, tipping forward slightly however, since, although there is depression of the plane of regard, the convergence is so slight as to induce small torsional action. As a third case, let us take the condition in which the eyes are directed to the page of a book in the ordinary reading position and that the gaze is directed so that the point of fixation is in the median plane and that the plane of regard is depressed 35 degrees. A mathematical calculation (see Stevens *Motor Apparatus of the Eyes,* page 184) gives the position of the page in relation to the plane of regard in which the horopter is most completely formed and it is found that the page should be tilted about 15 degrees beyond the right angle with the plane of regard or at about 105 degrees. It is thus possible to predicate the position of the horopter when the depression of the plane of regard and the convergence are known, if in addition the length of the base line between the nodal points is known. The above calculation can be verified by a simple experiment for those who can unite stereoscopic figures by convergence without the aid of a stereoscope. Two parallel vertical lines and at a distance of two and one-half inches are drawn on a card: this card is held so that in fixing the center of the lines the gaze is directed downward 35°. The card is to be held at about thirty inches from the eyes; one who is expert in such exercises will be able to unite the two lines at the normal reading point. If the two lines are not perfectly fused but are allowed to remain an eighth of an inch apart the angle at which the card must be held in order to render the two stereoscopic images parallel can be determined. In general it is found that the card must be tilted forward about fifteen degrees.

379. Savage, in his book entitled *Ophthalmic Myology,* has given a somewhat different method and mode of obtaining the horopter or *isogonal circle* as he terms it. The horopter, in the sense that it is the circle of binocular single vision, both direct and indirect, as shown in Fig. 186 (B), is based on three assertions:—(a) the macula of every eye is the posterior pole and the visual axis is the antero-posterior axis of the eye; (b) all indirect lines of vision cross the visual axis at the center of rotation; (c) corresponding retinal points have a common brain-cell connection and these points bear identical relationship in degrees to their respective maculas. In Fig. 186 (B) the circle is constructed through two fixed points and one changeable point. These fixed points are the centers of rotations of the eyes, *b* and *d*, and the changeable point that of direct fixation. The direct point of view, *c*, and its images *h* and *g* are connected by lines that cut the centers of rotation *b* and *d*. The secondary point of view, *a*, and its images, *j*

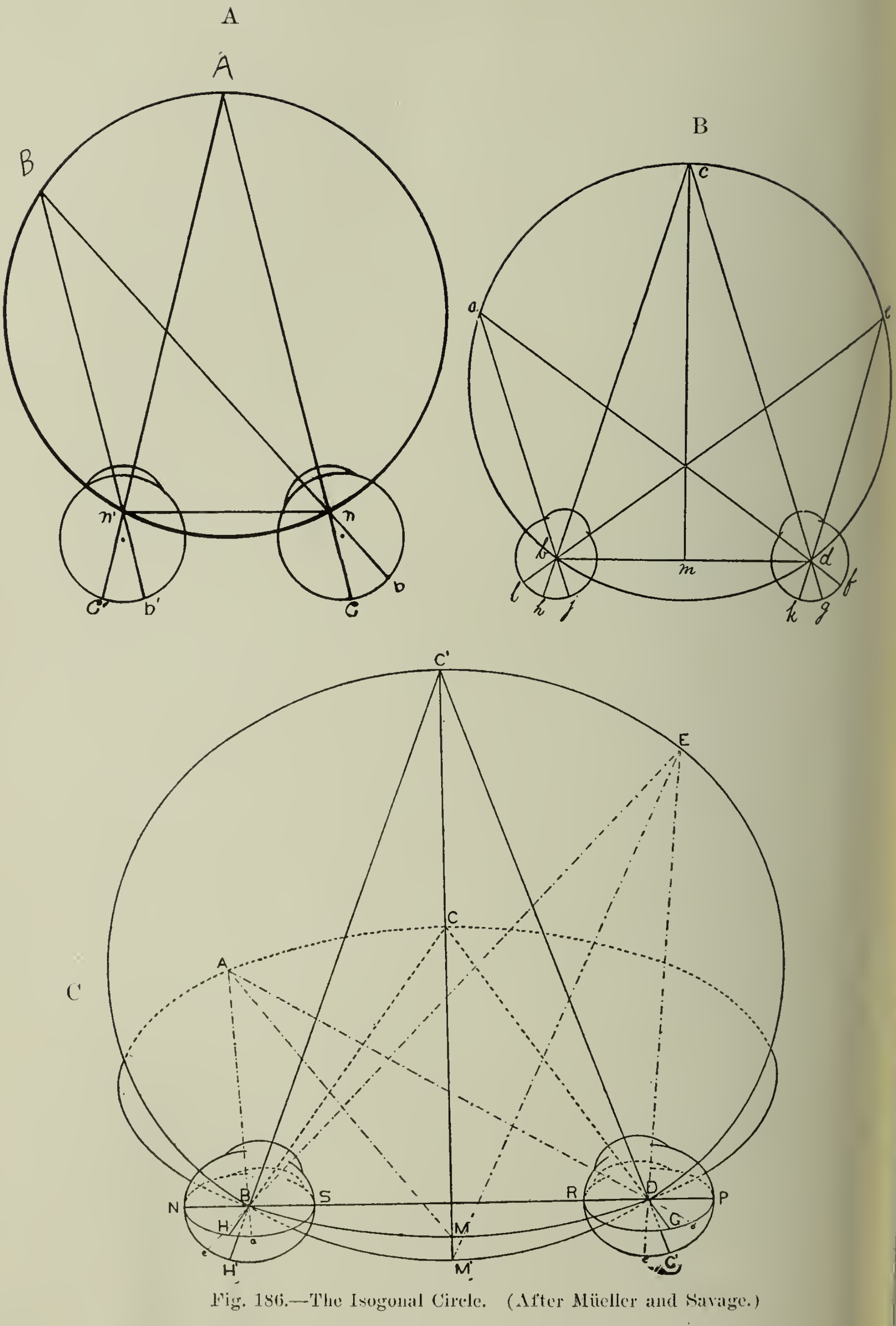


Fig. 186.—The Isogonal Circle. (After Müeller and Savage.)

and *f,* are connected by lines passing through the centers of rotation, *b* and *d,* and the secondary point *c* is connected with its images, *l* and $_{x}k$, by lines that cut the visual axes at the centers of rotation. All points on this circle, both direct and indirect, are seen under the same angle as is shown by the fact that each is measured by half of the arc *bd.* The figure also shows that the direct and the indirect points of view are related in degrees as are their respective images.

380. It is not inappropriate to pause at this point and to call attention to some of the teachings of Savage which are at variance with those of Helmholtz and others. Savage's first contention and assertion upon which he bases his isogonal circle is that the macula of the eye is the posterior pole and that the true optic axis is the visual axis. It is impossible to give, within the confines of this article, the reasoning upon which this statement is based. We can, then, but call attention to the main contentions of Savage in contradistinction to those of Helmholtz relative to ocular rotations. The following points are quoted from Savage's work.

Helmholtz	*Savage*
(1) The center of the cornea is always the anterior pole, and the center of the macula is the posterior pole only in ideal eyes.	(1) The center of the macula is always the posterior pole, and the center of the cornea is the anterior pole only in ideal eyes.
(2) The optic axis begins always at the central point of the cornea, passes backward through the center of rotation to the retina, rarely at the central point of the macula, but usually to a point between the macula and the optic disc.	(2) The optic axis always begins at the center of the macula, passes through the center of rotation and cuts the cornea, rarely at its center, but usually to the nasal side.
(3) The optic axis is the visual axis only in the ideal eye, and only then does the visual axis cut the center of rotation. Usually the visual axis misses the center of rotation by passing to the outer side of it, crossing the optic axis at the nodal point, and lying in only one meridional plane.	(3) The optic axis in all eyes is the visual axis and is the line of intersection of all meridional planes, hence it lies in the plane of every meridian.
(4) Visual lines are axial rays of cones of light, as is also the visual axis, and all these cross the optic axis at the nodal point. Even in ideal eyes the visual lines do not cross the visual axis at the center of rotation.	(4) Visual lines are not axial rays of light, but are radii of retinal curvature prolonged, all of them crossing the visual axis at the center of rotation, which is the center of retinal curvature.
(5) In passing from one point of view to any other, the visual axis of a non-ideal eye can not move in a plane of a meridian except when the rotation is directly to the right or left.	(5) In monocular motion every rotation plane is a meridional plane extended, and the visual axis always moves in this plane.

Helmholtz	*Savage*
(6) In cardinal and oblique rotation starting from the primary point of view or returning to it, the axis of any rotation lies in Listing's plane; the axis of rotation from one secondary point to another secondary point lies in a plane bisecting the angle between Listing's plane and the equatorial plane.	(6) The axis of every rotation, whether cardinal or oblique, whether from a primary to a secondary point of view, or vice versa, or whether from one secondary to another secondary point of view, lies in the equatorial plane.
(7) The object in space and its retinal image are connected by a straight line which crosses all similar lines at the nodal point, and never at the center of rotation.	(7) The object in space and its retinal image are always connected by a straight line which crosses all similar lines at the center of rotation and at no other point.
(8) The spacial pole, if on the same straight line with the two poles of the eye, can not be the direct point of view for non-ideal eyes.	(8) The spacial pole is on the same straight line with the two poles of the eye and is the direct point of view for all eyes.

And, again, the horopteric circle of Savage differs from those of Mueller and LeConte in that the indirect visual lines cross at the centers of rotation rather than at the nodal points.

381. As a result of his investigations, therefore, Savage defines an "isogonal surface" as follows: "The two visual lines, whether direct or indirect from corresponding retinal points, converging at any point on this surface, form the same angle as the two visual lines converging at any other point on this surface." All isogonal circles, whether primary or secondary, are alike in the following respects: (a) they are all constructed through two common points, the centers of rotation, of the two eyes; (b) they all have a common chord, the line connecting the centers of the two eyes; (c) they are all bisected by the extended median plane of the head; (d) all points on all the circles, belonging to one group, so located as to send light into the two eyes, will be seen as single points and (e) the two lines of vision connecting any secondary point, or any circle of a given group, with its two images, have the same angles as that formed by the convergence of the visual axes on the point of direct view.

XXI. MONOCULAR AND BINOCULAR PERCEPTION OF DEPTH

382. *The monocular perception of depth.* There are many ways in which a single eye can gain an idea of the third dimension: the eye, however, gives us no direct information as to the distance from which light comes to it. In the absence of direct information, however, a series of circumstances enables one to judge of the distance of an object, generally by an *unconscious judgment.* They are as follows:

(a) *Accommodation.* It is only in the judging of comparatively near objects that any assistance is derived from the conscious effort

of accommodation. As a rule a greater effort of accommodation causes one to think objects are smaller. When the eye is accommodated for distant objects, near objects do not appear distinct, hence an experienced observer might use this phenomenon to judge of the distance of an object. The importance of accommodation in the judgment of distance is small, however, because generally such long distances are dealt with that the difference of accommodation is insignificant: we know, for example, that for all distances exceeding one meter the variation in accommodation does not reach one diopter.

(b) *Visual angle of known objects.* The knowledge of the nature of objects often furnishes the observer with a means of knowing their distances. If the size of an object is known its distance can be judged from its angular size. When a man is seen a long distance off, he does not appear to be small because we know the size he should be and conclude that he must be a considerable distance away since the angular size is small. This experience is characteristic of the manner in which unconscious judgments are formed and is a process of education.

(c) *Mathematical perspective.* The gradual decrease in the size of similar objects and the gradual approximation of parallel lines is well known. The number of intervening objects also influences the judgment; hence distances over water appear smaller than over land.

(d) *Shadows and overlappings.* Shadows are often important in the judgment of distance. If a surface is illuminated, the luminous source must be in front of it and if the object casts a shadow on this surface it must be nearer the observer than the surface. Shading added to a drawing gives a better idea of its reality.

(e) *Aerial perspective.* The more distant the object the greater the depth of the atmospheric veil and the greater the depth of the atmosphere the bluer is the veil. When there is considerable water-vapor in the atmosphere distant objects, such as forests and hills, appear more remote than they in reality are and consequently seem larger than they are. In mountainous districts, in which the air is usually very pure, distances are judged to be less than they actually are. It is, again, a matter of common knowledge that the sun and moon appear larger when they are near the horizon. Their angular sizes remain constant however. Since the moon, near the horizon, appears larger than at the zenith although it has the same angular size, we may say that we judge it to be farther away. The illusion is due to aerial perspective, for the moon is seen through a much thicker layer of the terrestrial atmosphere when it is near the horizon than when it is at the zenith. It is probable, also, that the comparison

which is possible with terrestrial objects when in the horizon plays a part in the formation of the judgment.

(f) *Parallax.* This is by far the most important and valuable indicator in the formation of judgment as to the third dimension in uniocular vision. A single-eyed person who views an object not too far distant, while he cannot see the object as in binocular vision from two points of view simultaneously, yet can do so consecutively by moving his head from one position into another. An observer often sees, without being conscious that he does so, the relative movements of external objects and uses these to account for their relative positions. If, for example, an eye is displaced from *C* to *D*, Fig. 187, and the observer sees the object *A* displaced to the right relatively to the object *B*, *A* must be nearer than *B*. If, after having observed the

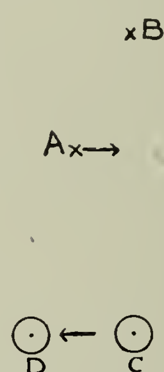


Fig. 187.—The Influence of Parallax.

objects *A* and *B* with the eye in the position *C*, the eye is closed and is again opened when in the position *D*, the observer realizes that *A* has changed position relative to *B*. This is sufficient to judge of its distance. The judgment is based upon the comparison of the successive retinal images. These images change position with each shift of the eye. But as all comparisons by memory are defective, one obtains a much clearer notion of the differences between the images and hence of the relief by a comparison of the images simultaneously with the two eyes. When binocular vision is enjoyed, each eye receives a perspective image of the objects situated before it; since the two eyes are not in the same place there are differences between the two images which are more pronounced the nearer the object is to the eyes. If, however, we look at a plane with both eyes the retinal images are identical. It is the perspective image of an object which permits

us to distinguish an object of three dimensions from a plane. This difference in images exists only at near points: if the objects are at a larger distance the retinal images are alike. A landscape, therefore, presents nearly the same appearance whether we view it with one or both eyes.

XXII. THE BINOCULAR PERCEPTION OF DEPTH

383. *The influence of convergence.* While parallax is the most important and valuable indicator in the formation of judgment of the third dimension *monocularly,* the *degree of convergence* which it is necessary to use to fix an object gives us the most reliable information binocularly as to the distance of an object. The degree of innervation employed is the criterion for the judgment of the direction of the visual line in uniocular vision; it is the innervation and not the sensation of the position of the eyes which is the guide. The absolute amount of convergence actually used is not of any great aid in the binocular perception of depth; it is solely for differences of convergence that there is an exact sensation, for to any volitional increase or decrease of convergence the mind is very sensitive. We can judge with great exactness whether one object is nearer or farther away than another; the judgment of absolute distance is extremely difficult.

Many experiments have been made to determine the rôle played by the convergence in the perception of depth and of distance. Wundt (*Lectures on Human and Animal Psychology*) placed the face of an observer before a box open at that side and having a horizontal slit in the other side through which both eyes could look at a white screen, the surrounding objects being excluded from the field of view. A vertical thread, kept taut, hung between the slit and the screen. In the experiments which were made to determine to what degree of certainty the comparative distance of the thread, when it was made to approach or recede, could be determined, Wundt and his collaborators were careful, whenever the thread was moved, to close their eyes during the movement and upon opening them to look first at the screen and then at the thread. Such experimentation showed that, on the average, one could determine the approach or the recession of the thread to within $1/50$ of the distance and that the degree of accuracy increased with the degree of convergence of the visual lines. To illustrate: if the thread hung at a point fifty centimeters from the eyes it was found possible to determine the fact that it was nearer when the thread was moved up to the forty-nine centimeter point. Bourdon (*La Perception Visuelle de l'Espace*) arrived at conclusions which do not vary greatly from those of Wundt. He found that a convergence

of eight minutes for each eye, the object fixed being 1.08 meter distant, was needed to recognize the fact of an approach or recession of a very small object. The fact that the nature of the change of adjustment of about one-quarter of a degree between the two visual lines could be constantly detected, after an interval of time during which the eyes had been variously moved, shows the sensitiveness or delicacy of the sense of movement of the visual apparatus.

384. *The stereoscope.* In 1833 Wheatstone enunciated the principle on which the stereoscope is constructed. His statement is as follows:—

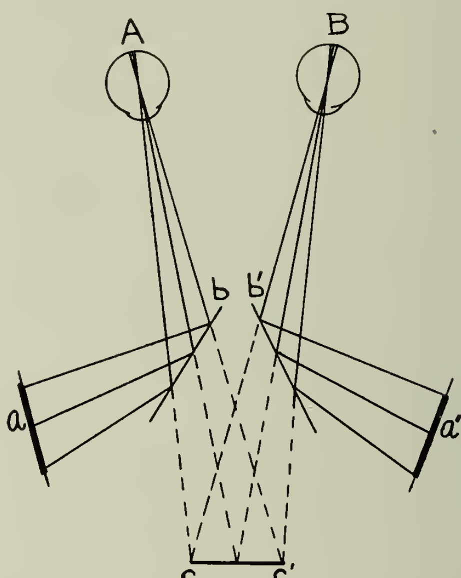


Fig. 188.—Diagram Representing the Principles of Wheatstone's Stereoscope.
a, a′, The cards with the two pictures.
b, b′, The mirrors.
c, c′, The apparent position of the combined images.

"A solid object being so placed as to be regarded by both eyes projects a different perspective figure on each retina; now, if these two perspectives be actually copied on paper and presented, one to each eye so as to fall on corresponding parts, the original solid figure will be apparently represented in such a manner that no effort of the imagination can make it appear as a plane surface." Wheatstone's stereoscope consisted of two glass mirrors fixed in frames and adjusted to an angle of ninety degrees with each other. The drawings are placed in suitable holders at each side and make an angle of 45° with the mirror on the same side respectively. The image of each drawing is then seen

by reflection; by means of mechanical devices the drawings may be moved to a greater or less distance from the mirrors and also their angles to the mirrors may be changed. The two pictures may thus be presented to the eyes when adjusted in parallelism or in convergence. The diagram, Fig. 188, represents the principles of the reflecting stereoscope: a and a' represent the cards with the two pictures; b and b' the mirrors and cc' the apparent position of the combined images. In order that the relief may not be reversed or pseudoscopic it is necessary to present to the left eye the image outlined for the right eye, since the mirrors reverse the images.

385. Each of the images of the stereoscopic picture is drawn in such a way as to form in the eye a retinal image like that which would be formed there by the object itself. Distant objects are represented by identical images, while the images of near objects are different. In

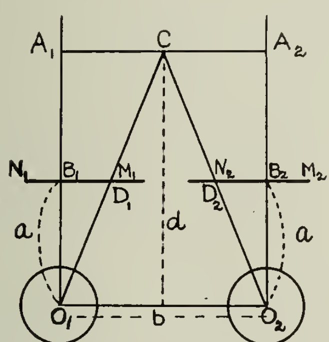


Fig. 189.—Illustrating Stereoscopic Parallax.

order to account for the way in which objects are represented on stereoscopic images, let us suppose two plates, N_1M_1 and N_2M_2, which are transparent, placed in front of the eyes at the position which the stereoscopic cards ordinarily occupy (Fig. 189). Straight lines directed toward the eyes are drawn from all exterior points: two such lines start from each point. The points at which these lines cut the corresponding plate is the reproduction of the exterior point. If this exterior point lies at infinity the two straight lines are parallel and the distance B_1B_2 between these points is equal to the base line O_1O_2. If we place the two transparent stereoscopic figures over each other so that the two reproductions of the same point situated at infinity overlap, then the reproductions of all the points situated at infinity coincide two by two. If, however, the exterior point C is not at infinity, the distance between the two reproductions is less than that of the eyes. The difference is known as *stereoscopic parallax.* The

parallax of the point C is, as in the figure, $B_1D_1 + B_2D'_2 = E$. If we designate the distance between the two eyes by b, that of the object C from the plane of the two eyes by d and the distance of the plates from the eyes by a, we have

$$\frac{b - E}{d - a} = \frac{b}{d} = \frac{E}{a} \text{ or } E = \frac{ba}{d}$$

This shows that the parallax increases with the distance between the two eyes and that it is greater as the object is nearer the observer.

Fig. 190 gives the plan of Brewster's stereoscope. A and B are the

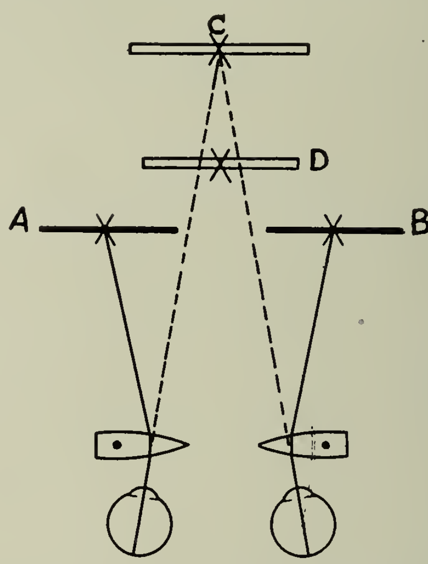


Fig. 190.—Plan of Brewster's Stereoscope.

pictures which are taken from slightly different points of view. Hence the distance between identical objects in the foreground of the two pictures is less than between identical objects in the background. To fuse the former more convergence is required than to fuse the latter. Foreground and background objects cannot be fused simultaneously. If this were possible the sensation of *relief* would disappear. When looking at the foreground of the landscape pictured there is a physiologic diplopia of the background and vice versa. By way of explanation at this point, it has been stated by Dove and other experimenters that objects appear solid when seen by the instantaneous illumination of an electric spark; if so, then the appearance of solidity must be due to the physiological diplopia of those portions which are

not seen single. The quantitative perception of depth and the notions of relief require that the eyes should unite successively different parts of the object by consecutive increase and decrease of convergence. As a result of this, many persons discover with a stereoscope that the appearance of relief does not come until after a few movements, involving changes of convergence, have been made. If one takes a lead-pencil, held pointing forwards in the median plane and a little lower than the plane of the eyes, and fixes the far end of the pencil, the near end is seen double. By converging to a point at the center of the pencil both ends exhibit diplopia of half the magnitude which the far end at first showed. By converging still more so as to look at the near end of the pencil the far end exhibits homonymous diplopia. *Hence we conclude that if both foreground and background objects in stereoscopic images could be simultaneously fused there would be no sensation of relief.*

In the stereoscope proper, a decentering of the lenses outwards enables the eyes to converge somewhat, as for instance to the point *C*, Fig. 190. The convex lenses produce a certain magnification and their prismatic effect renders it unnecessary to make the visual lines parallel. As a general rule, however, the single united image of the stereograms is projected to a position *D* which is closer to the eyes and to the pictures *A* and *B* than is the point *C;* this occurs because of the knowledge that the observer possesses of the size of the stereoscope. The effect of the stereoscope is to give an idea of depth such as no other method of representation can. (See article by Isadore Franklin, M. D., on "Stereoscopic and Perspective Vision," *American Journal of Ophthalmology,* page 236, 1918.)

386. *Antagonism of the visual fields.* Under ordinary circumstances there are formed in one eye images of the same objects as in the other. As long as we place in the stereoscope images of real objects only we simply see the relief. When the images placed in the two fields are so different that they cannot be fused as, for example, if there is presented to one eye horizontal lines and to the other vertical lines, there will be observed the phenomenon known as antagonism of the visual fields. It is sometimes one field and sometimes the other which predominates; while one field is in the supremacy the other is suppressed and is not seen at all. The change from one field which has been dominant to the other takes place under external influences; a winking of the lids or a change in the direction of the gaze often brings about the change.

387. We shall now consider briefly two *haploscopic* fields containing diagrams which, upon being united, partially coincide with each

other; let us choose fields such as those diagrammed in Fig. 191 *A* and *B*. There is on the left in Fig. 191 a vertical black rectangular field perpendicular to the visual field and on the right a field similar in all respects to the first one except that it lies horizontally. In the center of these fields is a white cross. These crosses are made to coincide with each other: in the binocular field there will be formed large black

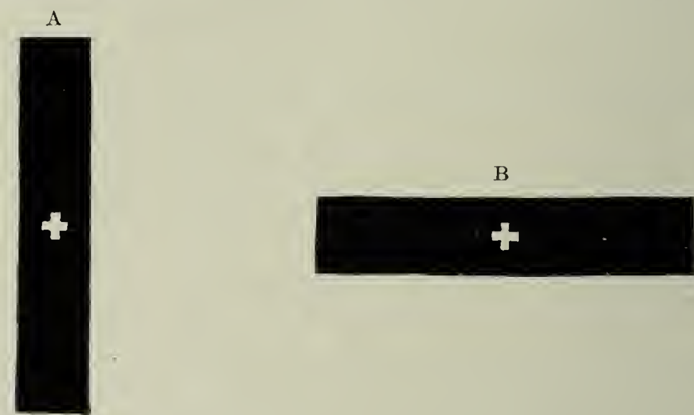


Fig. 191.—Diagrams for Obtaining Union of Two Haploscopic Fields.

crosses which are roughly represented in the three diagrams of Fig. 192, the fixation crosses being omitted from the diagrams. At those parts where the contours of one black band overlap those of the other there is a constantly wavering appearance as if there were a continuous rivalry between the two impressions which the object can convey. The impression is not that of an evenly black or evenly gray cross.

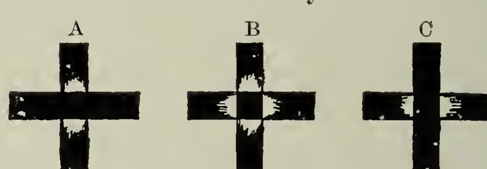


Fig. 192.—Illustrating the Effect of the Union of the Two Haploscopic Fields Shown in Figure 191.

In the portions where the black bands overlap each other one sees now the contour of one band and now that of the other and at times both at once as shown in the central diagram of Fig. 192. The condition in which the borders of the two objects make themselves particularly prominent is known as the *rivalry of contours.* Close to an edge there is always seen the brightness of the object whose border is at the time prevailing. The inner square of this figure is always black; just outside of each contour there is a white spot which gradually

shades into black again. If the attention is fixed upon the right-hand (the horizontal) band, then the first of the diagrams in Fig. 192 is

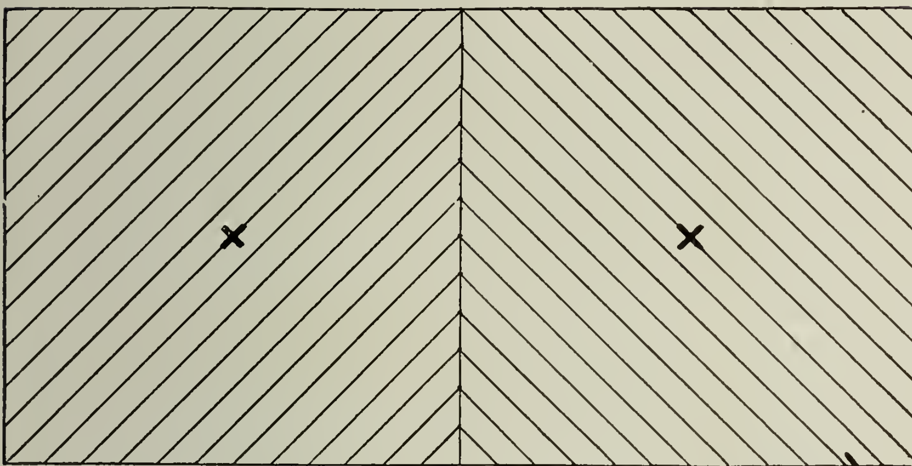


Fig. 193.—Another Type of Diagram for Obtaining Union of Two Haploscopic Fields.

obtained: if it is directed upon the left-hand band then the third of the diagrams of this figure is seen.

388. In the case of the diagrams represented in Fig. 193, each field

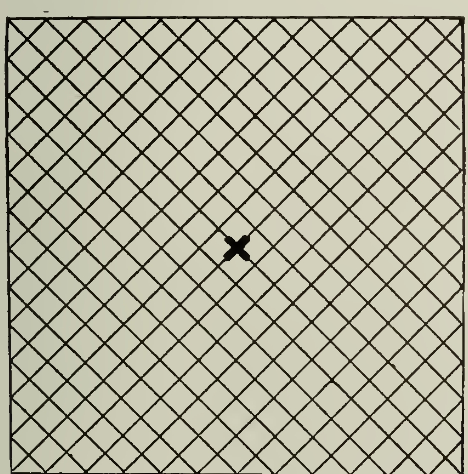


Fig. 194.—Illustrating the Effect of the Union of the Two Haploscopic Fields.

contains a series of black lines equally spaced and inclined at an angle of 45° with the visual plane. Upon uniting these haploscopically there is *not* seen a field of squares such as is shown in Fig. 194, but

simply a wavering image whose separate parts correspond to the right-hand and to the left-hand member in turn. This occurs when no distinct direction is given to the attention. But if the attention is fixed upon either half of the diagram, then the portion which is under regard distinctly prevails for some moments over the other. Helmholtz explained this rivalry of visual fields as caused by a wandering of the attention. He finds in the influence of contours the effect of habit which leads one to examine particularly the contours of an object in order that the object may be recognized as quickly as possible. These phenomena indicate that we become conscious of the contents of each field of vision distinctly and separately from those of the other. They likewise prove to us that such fusion as does take place is not conditioned by the organic structure of the brain and also show that when a fusion of the sensations of the two fields does not occur in the interests of perception of the third dimension, each field of view preserves its own identity and independence.

389. *Theories of the production of relief.* The theories of corresponding or identical points and the theories as to the nature of the identity have been discussed in some detail in preceding sections. Briefly, then, in resumé it may be stated that we consider one point of the retina of one eye as corresponding to, or identical with, a point of the other eye when the images of the same exterior point, falling upon these two retinal points, are blended into a single point. It is evident that the two foveas are corresponding points since the object fixed is normally always seen single. Johannes Müller has given the following rule for finding other identical points: Suppose the retina divided into quadrants by a horizontal and a vertical meridian, both passing through the fovea. Two points, then, having the same longitude and latitude are identical. The question of why two points are corresponding while two others are not has been the subject of much discussion. Many advocates of the theory of identity suppose that there is an anatomical relation between two corresponding points, by assuming that the nerves conducting the impressions from two such points unite on their way to the chiasma into one which carries the impression to the brain. The theory of projections has been advocated by others: under this theory, for example, a point on the right retina five degrees to the left of the fovea localizes its impression in space as five degrees to the right of the point of fixation, while a point on the left retina situated five degrees to the left of the fovea localizes its impression in the same direction as in the case of the other eye; since the two impressions are projected in the same direction they are blended into one.

390. After the invention of the stereoscope and after various studies upon the production of relief had been carried out, the notion of corresponding points fell into disfavor since the experiments with the stereoscope seemed opposed to the doctrine of identical points. If we take, for instance, a stereoscopic presentation of two points, A and B, both of which are situated in the median plane but one more remote than the other, it will then be seen upon fixing the more remote object A that the images of B are not formed on identical points. For in one eye its image is to the right and in the other to the left of the fovea; however, it will be seen single and in relief and hence the single image of B will appear closer than A. On account of these contradictions Wheatstone favored the theory of projections. It remained to Javal to clear up, in large measure, this question and to give a satisfactory theory of relief.

391. In the *theory of the production of relief* as given by Javal we find two essential factors: (a) the neutralization or partial suppression of one of the images and (b) the influence of the ocular movements as emphasized by Brücke. We have previously referred to the rôle which the suppression of the images plays in binocular vision and comment has been made upon the suppression of one of the images which occurs when different images fall on corresponding points of the retinæ. Sometimes the image of one eye and sometimes that of the other is seen. While the image of one eye is seen, the corresponding part of the image of the other eye is lost. There is in normal cases ordinarily an alternation of suppression exhibiting itself as antagonism of the visual fields.

392. Tscherning, in writing on Javal's theory of the production of relief, says:—"Bruecke was the first who insisted on the great importance of the ocular movements for the perception of relief. Anyhow, it is certain that without them we could have only a very vague notion of it. Looking into a stereoscope, especially if the images are difficult to fuse, it is only after I have permitted my look to wander for some time on the figures, fusing sometimes the images of the distant objects, sometimes those of the near objects, that relief appears to me. As long as the sensation of relief is not produced I see double, sometimes the near objects, sometimes the distant ones; but at the moment when relief appears, I see all of them single. Certain authors claim that they have observed relief by illuminating the stereoscopic images with an electric spark, the duration of which light is so short that all ocular motion is necessarily excluded. This would certainly be impossible in my case for there always elapses a certain time before the real illusion, which does not prevent me from being able to form all at once a vague notion of relief.

"According to Javal, it is necessary, indeed, to distinguish between the *idea of relief,* which is produced by the fact that we see near objects in double cross images, and the *measurement of relief,* which depends on the *sensation* of the degree of innervation necessary to converge towards the near object. To account for the manner in which we come to obtain the sensation of relief, it is preferable to use images which are quite difficult to blend, the stereoscopic parallax of the objects represented being quite strong. We immediately fuse the images of distant objects, and all the others appear in double images. We then allow the look to stray on the figure, which forces convergence more or less, according as the object is represented more or less distant. After having continued thus for some time, relief manifests

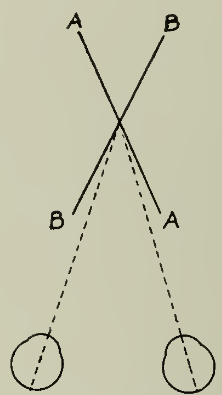


Fig. 195.—Illustrative of the Discussion as to the Part Played by a Directing Eye in the Production of Relief.

itself almost in the same way as we can, with closed eyes, obtain a very distinct idea of the form of an object by feeling it with the fingers. At the same time that relief appears, the double images disappear; the image of one or the other eye is suppressed. If one of the eyes plays the part of the *directing eye,* it is usually the images of the other eye which are suppressed, unless the image of the preponderating eye is much more peripheral than that of the other. In cases in which this preponderance is not developed, the double images seem to appear following the law of Javal: we suppress that one of the images which occupies the smallest retinal surface. We can account for the manner in which we suppress the images by looking at a rule which is held obliquely before the eyes, so that it presents a greater surface to one eye than to the other. Whether it occupies the position *AA,* Fig. 195, or the position *BB,* it seems to me, seen

binocularly, to have the same appearance as when I close the left eye. Persons in whom the preponderance of one eye is not developed see the rule binocularly, as it is presented to the left eye, if it occupies the position AA. In the position BB they see it, on the contrary, as it presents itself to the right eye.

"The discussion of the two theories of binocular vision, that of *identity* and that of *projections,* has not yet closed. The explanation of Javal is applicable in reality as well to one as to the other. We *can* imagine the projection learned by experience; and even the fact of always projecting the images of the two foveas at the same place, the foundation stone of binocular vision, may be something learned. It is, perhaps, the superiority of the fovea, as to visual acuity, which causes us to always bring the images of the object which interests us to form themselves on both foveas, and we may thus have been led to always localize the impression of the two foveas at the same place. On the other hand, the advocates of the theory of identity take their stand on the anatomical observations of the semi-decussation in the chiasma, and especially on comparative anatomy, which shows that in many animals—fish, for example,—whose eyes are placed so as not to have a common visual field, the optic nerves cross completely. Clinical observations in hemianopsia, especially those of partial hemianopsia, are a further argument in favor of this theory. The study of the vision of strabismic patients, which is perhaps the best means of deciding the question finally, shows that, in consequence of a false position of the eyes, there may be developed a kind of correspondence between two retinal points which, under ordinary circumstances, are not corresponding: but this relation never assumes the character of true binocular vision with fusion, and it sometimes suffices, in a person who has squinted since childhood, to place the eyes in an approximately correct position, in order that, in the course of a fortnight, correct projection may gain the upper hand." (Tscherning, *Physiologic Optics,* translation by C. Weiland.)

393. *Tests for binocular vision.* Worth, in his book on *Squint,* describes a simple test which is an adaptation of Snellen's colored glasses and which he calls the "four-dot test." A piece of plain ground glass is covered on one side with black paper in which four round holes are cut. The lower hole is left clear. The upper one is covered with red glass and the two holes at the right and the left are covered with green glass. The whole arrangement is then mounted in a box which contains an electric lamp. The patient, seated at twenty feet, wears a trial frame in which a red glass is inserted before the right eye and a green glass before the left one. If he sees two dots, white and red,

he is using the right eye only; if he sees three dots, the white and two greens, he is using the left eye only; if he sees four dots he is using both eyes and enjoys binocular vision or simultaneous macular perception. If he sees five dots, one red, two greens and the white seen double, he has diplopia.

394. Another excellent device is the *amblyoscope* due to Worth. This instrument consists of two halves joined together by a hinge. Each half is a short brass tube joined to a longer tube at an angle of 120°. At the angle of junction there is a mirror: each half of the instrument has at its distant end an object carrier and at its near end a convex lens of five inches focal length. A brass arc connects the two parts of the instrument so that they can be brought together for a convergence of the visual axes up to 60° or separated for a divergence of 20°. The instrument should be adjusted for parallelism of the visual axes. In the object carriers are to be placed slides, one of which contains a slit and a small cross to its left while the other carrier has a similar slit and a dot to its right. If the patient sees the two slits as one and at the same time sees both the dot and the cross he has simultaneous macular perception. If in addition the tubes of the instrument can be converged or diverged and the slits still fused, the patient has true fusion with some degree of amplitude. The sense of perspective may likewise be tested by the use of proper slides.

395. The *Hering drop test* provides a method of examining the notion of relief rather than of measuring it; it is a test of the sense of perspective. The apparatus consists of a shallow box open at both ends or else two tubes suitably joined together. Two arms then project from this box, opened at both ends, or from the sides of the tubes respectively. The ends of these projecting pieces are joined by a thread on the middle of which is a bead. The patient places one end of the box or of the tubes close to his eyes and looks at the bead. The examiner then drops small objects, such as marbles, sometimes on one side of the thread and sometimes on the other. If stereoscopic vision exists, i. e., if the sense of perspective is developed, the patient will always give a correct answer as to whether the object is dropped on the near or far side of the bead. If not, approximately half the answers will be correct for they will be largely guesses. The principle upon which this test depends is simple: the box cuts off all view of surrounding objects and if the size of the falling objects is varied their apparent sizes can give no information as to their distance. The view of the falling object is too brief to permit of accommodation or convergence or any lateral movement of the patient's head. The patient

has, therefore, no aids to his judgment of distances and hence depends upon his sense of perspective entirely.

396. The well known *"bar-test"* of Javal, in which a pencil or similar obstacle is held midway between the patient's eyes and a page of print to see whether the observed party can read continuously without sudden movements of the head in order to avoid the obstacle, is a test of *rapid alternate binocular vision* and *not* a test of *stereoscopic* or *single binocular vision.* If both eyes have sufficient visual acuity but are not in co-ordination there will be either a bobbing of the head or a pause when the deviated eye has to take up fixation, followed, in turn, by another pause before the good eye can resume the reading.

397. *Unconscious conclusions and optic illusions.* We have seen that the psychical processes in vision come as a result of definite physical actions and we have pointed out that, by means of the stereoscope we are able to explain, by the comparisons which can be made between experiments made with such an instrument and our ordinary experiences, many of the phenomena of vision which would otherwise not be understood. The character of the perception obtained in vision is not apparently determined so much by the image formed upon the retina as by the movements of the eyes, although it does not follow that the line of sight must compass every detail of the figure seen. The apparent size, distance and even color of an object are influenced considerably by processes of mind and these mental processes differ in character under different circumstances. Conclusions drawn from experience, contrasts, comparisons of environment and a variety of psychical processes enter into the final conception which the mind entertains. The acts of motion of the eyes constitute the basis upon which the idea of space as recognized by the visual sense is founded: this does not mean, however, that motion is necessary in every instance of judgment of space but that the experience which has been gained by the acts of motion is essential. Hence, while it is probable that the visual notion of space is the result of movements, it is not possible to execute all the movements necessary to obtain an idea of the perspective of a complex body in the infinitely short time in which such ideas are formed; consciousness is not the result of a single process but actual movements and potential efforts, as Stevens states it, are combined in the formation of the idea of visual space. The experiment of Dove showed that an object illuminated by an electric spark may be located in space although the light of the spark has not persisted long enough to have enabled the eyes to adjust themselves for the object. Hence the knowledge of the distance and direction of the impression received by the retinæ permits of a judgment of the

extent and direction of the movement which would *have* to be executed in order to accomplish the adjustment.

398. A study of visual phenomena leads us to the conclusion that our knowledge of our surroundings is the result of mental deductions from physical signs and that the impressions received by the visual sense are simply so many symbols from which the mind draws certain conclusions. This method of drawing conclusions can be illustrated by the effects produced by certain combinations of diagrams the parts of which, when examined under ordinary circumstances, appear incapable of presenting the appearances which they assume under other circumstances.

Two ideas are in general entertained as to the manner in which objects are perceived by the eye. According to the popular conception, rays of light from the object pass into the eye and form an image of the object on the retina or cause an impression of an image which

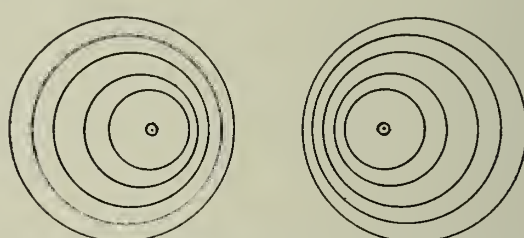


Fig. 196.—Diagram for Use with Stereoscope to Illustrate the Manner in Which Unconscious Conclusions are Reached.

is transmitted from the retina to the brain; this notion involves the transmission of the picture or impression as a whole. The second idea is that the impression caused by the light transmitted to the retina acts as a "finder" and that the retina, with its functions of recognizing light and color, acts as a guide to the muscles which move the eyes. These movements of these muscles in bringing the most sensitive portion of the retina into direct relation with various parts of the object constitutes an essential element in the ultimate mental impressions made.

399. Two series of rings, such as those shown in Fig. 196, when inserted in the stereoscope or when fused without its aid, give the impression of a solid truncated cone in space with the smaller base nearer the observer. The centers of all the circles, except those of the very small innermost ones, are displaced toward the point geometrically the center of the two sets of circles. Hence different amounts of muscular contraction are demanded for the convergence of the two

eyes observing the different pairs of rings. The cone does not appear complete, however, but has its apex cut off, while in the center of this section is a dot exactly in the plane of the section. The dot (or minute circle) does not complete the cone because each of the dots is exactly in the center of the smaller ring and the convergence of the eyes for the combined image of the dots is exactly the same as the average convergence or the convergence for the imaginary centers of the rings. This influence of muscular contraction and convergence makes itself felt if these two sets of circles are viewed in the plane of the page at any convenient distance, since the whole figure conveys the notion of objects in space tilted obliquely toward each other by virtue of the knowledge we possess that such objects in space would be seen under slightly different angles of convergence for different centers of the various contours upon the surfaces. We draw the same

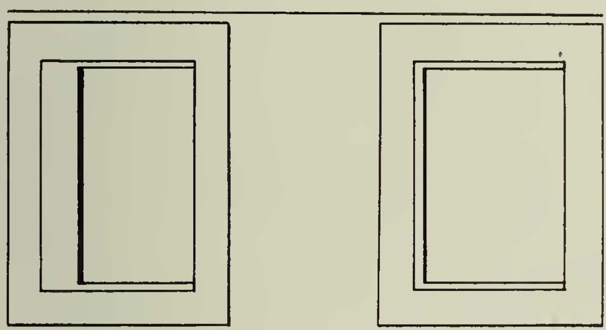


Fig. 197.—Illustrative of Mental Conclusions from Muscular Adjustment.

unconscious conclusions with respect to drawings and what they represent as we do with respect to stereoscopic diagrams under the stereoscope by reason of the knowledge we possess of the acts of motion of the eyes which are necessary to the formation of our judgment of the object and its position as actually existent in space.

400. Let us consider briefly the diagrams presented in Fig. 197. These figures are not symmetrical, but if they are observed through the stereoscope the framework is perfectly united at once and after a moment the heavy lines also but the latter swing backward like an open door. We can elucidate this phenomenon and give a process of reasoning by which these figures can induce this conception.

Suppose, in Fig. 198, the eyes A and B are directed toward cd, which represents the space of a door, and ce, which represents the door swung open. In looking at the door space the eye A moves through an angle cAd and the eye B makes an angle cBd. Directing in turn the

eyes to the door proper it will be seen that the eye A will make a smaller excursion, (from c to e') and the eye B will also make a movement less than cd but greater than ce' and measured by cd'. Hence, in looking at an open door as shown in the figure the eyes make equal movements for the open space but shorter and unequal movements for the opened door. These are the elements in the stereoscopic picture.

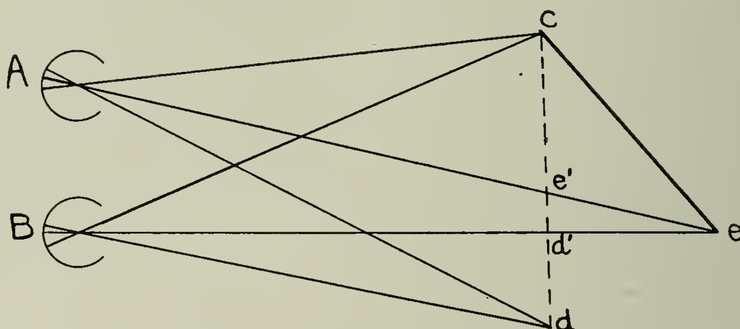


Fig. 198.—Diagram Explanatory of the Phenomena Discussed under Mental Conclusions from Muscular Adjustment.

These elements in turn conform to the everyday experience in ocular adjustments and hence the mind arrives at the conclusion that the object seen does not differ from what would actually induce such ocular movements. If we look at the two pictures presented in Fig. 197 we come unconsciously to the conclusion that the left hand diagram represents a door ajar while the right hand figure represents a door very

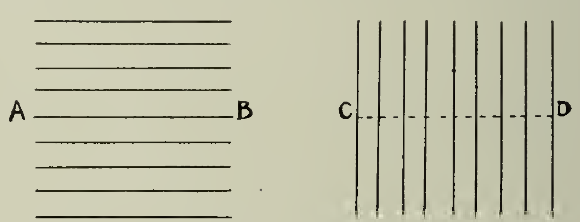


Fig. 199.—Illusion of Height and Breadth.

nearly completely closing up the door space. We can, then, from very simple line diagrams and crude drawings very readily gain a conception of space representations through our knowledge of the ocular movements and innervations which would be necessary if the objects outlined in the drawings were actually seen in space.

401. In Fig. 199 we have drawn two equal squares, one marked with horizontal and the other with vertical lines. The square with the horizontal lines appears appreciably higher than its mate, while the

square with the vertical lines is appreciably broader than the other. In neither case do the squares appear equal on all sides. The single effort of sweeping directly from one extreme of an object to the other without a halt or obstacle does not produce an effect in the course of the muscular impulse as when the eye passes from one side of the object to the other by a series of smaller exertions. That is, repeated small movements are of more consequence than a single muscular sweep of extent equal to the sum of the smaller movements. The passage

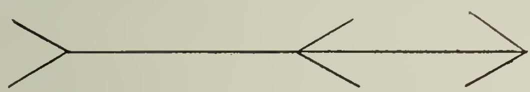


Fig. 200.—The Mueller-Lyer Illusion.

from A to B is uninterrupted, while the passage from C to D (Fig. 199), although equal to that from A to B, is interrupted and appears greater. This same phenomenon and explanation occurs in the Müller-Lyer illusion in Fig. 200. The two parts of the horizontal line are of equal lengths yet the line from which the prongs diverge in a direction partly continuous with the main line appears considerably longer than the part enclosed between those short containing lines which diverge backwards upon each other. The impression of the extent of the object is modified in the contrast in the muscular sense between

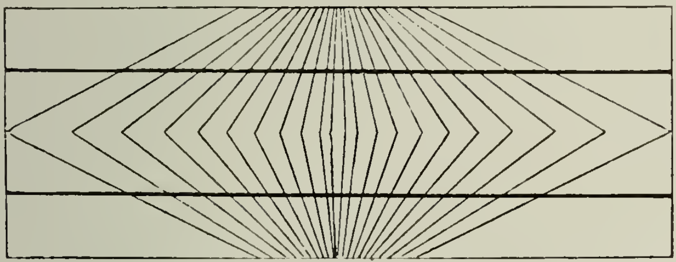


Fig. 201.—Convexity of Straight Lines. (After Hering.)

an action unimpeded and extended beyond the point of measurement and an action suddenly stopped and turned back upon itself. In looking at Fig. 200, then, we see that in the first place the eye follows the course of the main line and encounters the diverging lines with no sudden stoppage in its course and passes by a slight modification along one of the divergent lines. In the second case, however, in the ocular movements the attention is directed to the retrograde line and the movement is stopped before the extremity of the line is reached.

402. In the two accompanying diagrams, Figs. 201 and 202, a straight line does not appear as a straight line and parallel lines do

not seem to be parallel. In the first of the two diagrams the lines appear to bow away from the eenter point and in the seeond ease they are apparently bowed toward the eenter of the figure. The explanation of these phenomena lies in the explanation already offered with respect to preeeding optical illusions. If a movement be eontinued beyond the point of termination the distanee appears greater than if the oeular movement is suddenly arrested and turned back. "In the ease of Fig. 201 the angles on the outer sides of the lines permit the movement to slide without sudden arrest with the result that that side of the long line appears elongated and the line also approaehes the branching lines, not beeause the picture on the retina brings the long line in eloser relation to the branehes, but because in the movements required the two lines forming the aeute angles are brought in relation

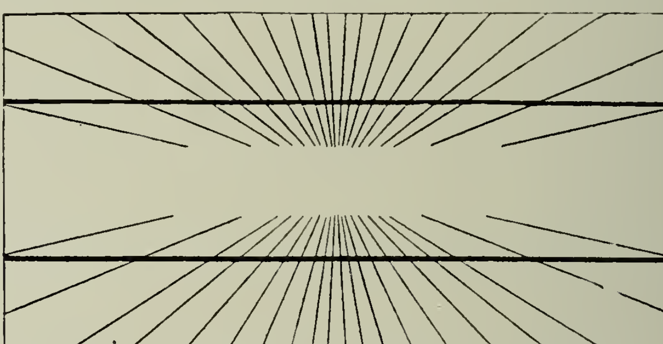


Fig. 202.—Concavity of Straight Lines. (After Wundt.)
From Stevens' Motor Apparatus of the Eyes. Copyright, F. A. Davis Company, Philadelphia.

to eaeh other and, as Helmholtz remarks, there is a mental contrast of the angles between the direct and the oblique lines. The two long lines appear to approaeh toward the center and to diverge toward the extremities. The other figure shows the angles reversed, with the effeet of ehanging the apparent curves of the really straight and parallel lines." (Stevens.) In explaining the geometrie illusions of Hering (Fig. 201) and Wundt (Fig. 202), Hering argues that the separation of two points removed from each other by a small distanee is estimated at a greater relative value than that of points further removed provided there is no dividing point between these latter. In a similar manner a small are has a greater relative value than a greater one proportionately in pereeption; henee acute angles are overestimated and obtuse angles are underestimated. The movements of the eye for an aeute angle are incomplete and suddenly arrested but for an obtuse angle they are nearer in unison with the full extent of the lines bound-

ing the angles. That the eye is or may be arrested at a point along its course in the estimation of an acute angle and therefor overestimates its value is made plausible by investigations by Judd on the Müller-Lyer illusion. In these researches, photographs showed that the movement of the eye in the direction of the acute angle is arrested before the point of the angle is reached.

403. In the figure of Zöllner, (Fig. 203) the long straight lines which are parallel seem to converge and diverge upwards following the direction of the small oblique lines. The explanation lies again in the judgment giving too great a size to acute angles.

Fig. 203.—Zöllner's Figure.
From Stevens' Motor Apparatus of the Eyes. Copyright, F. A. Davis Company, Philadelphia.

404. In many of these cases of optic or geometric illusions the phenomena of *irradiation* may furnish sufficiently satisfactory explanation. Helmholtz has pointed out how these phenomena, by the laws of contrast, might induce such effects. Quite recently Alfred Lehmann has investigated the influence of irradiation upon geometric illusions and asserts that the illusion represented in *B*, Fig. 204, must be entirely due to irradiation. The two lines in *B* appear to converge toward each other at the top of the figure, the fine connecting lines being transformed into a series of zig-zag lines as represented in *E*. Lehmann believes that the highly and feebly illuminated spaces, which are in close juxtaposition, permit irradiation from the clear to the obscure squares. In the case of the series of squares represented at *C* we have a connecting line in each set which is so broad that the effect of irradia-

tion does not extend to the black squares and hence there is no illusion. And again at A, where there is no marked contrast in the illumination, there is no illusion.

There are also illusions as to movements of exterior objects which often occur because of a false judgment of the movements which the observer is himself making. A familiar example is that of the apparent movements of objects as seen from the window of a train in motion: the observer does not take into account his own change of position and hence attributes the motion to the exterior objects.

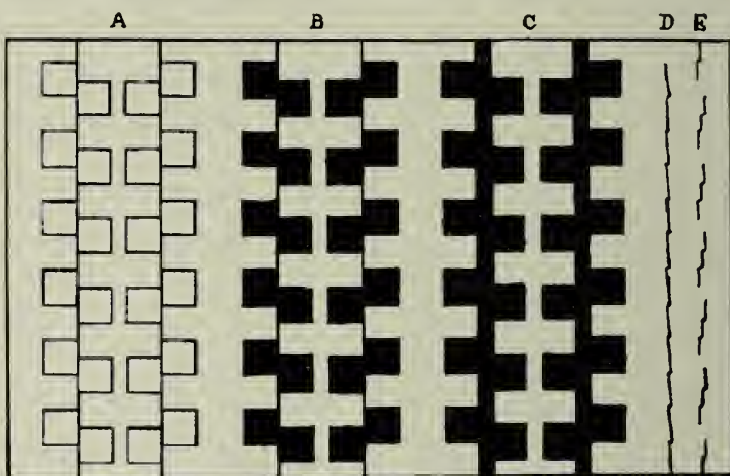


Fig. 204.—Irradiation as a Cause of Geometrical Illusions. (After Lehmann.) From Stevens' Motor Apparatus of the Eyes. Copyright, F. A. Davis Company, Philadelphia.

PART FIVE

BINOCULAR VISION AND DISORDERS OF THE MOTILITY

XXIII. DIPLOPIA

405. Binocular vision has been briefly defined as single vision with two eyes. The placing of the two eyes in such a position that the image of the object under regard shall fall upon the fovea of each eye is as voluntary as the adjustment of the accommodation. Normally, then, when both eyes "fix" the object, each eye has an image of the object on its fovea and these foveal images or impressions are transmitted to the brain and fused as one image in the visual centers: vision is single because the images impress corresponding portions of the two retinæ and are received by the brain as one. This condition is spoken of as equipoise or *orthophoria* and the eyes are said to be "in balance."

When, however, the image is focused upon portions of the retinæ that do not correspond as, for example, when one fovea only fixes an object and its mate receives the image of the same object on a part of its retina remote from the fovea, the brain is unable to fuse them and therefore is cognizant of two separate impressions; this condition is spoken of as *diplopia.* When the retinal impression of the non-fixing eye is close to the macula the patient is frequently conscious of blurred vision and of muscular efforts to make this eye also fix. Under such conditions the patient has headaches and other symptoms which are the usual accompaniment of asthenopia. In many cases where the two eyes fail to fix the object simultaneously diplopia does not occur since nature, abhorring doubleness of vision, allows one image to be ignored or suppressed. Diplopia may be removed by placing a prism before one eye (or divided between the two eyes) and thus causing the rays that pass through it to be deflected to such an extent as to fall upon the fovea of this eye which, under these conditions, corresponds to the other eye and two objects are no longer seen. And again, artificial diplopia may be produced by placing a prism before the eye in such a position and of such a degree as to prevent the transmitted rays from falling upon corresponding points.

406. *Homonymous and heteronymous diplopia.* There are two forms or varieties of diplopia known as *homonymous* and *heteronymous* (or crossed). In order to properly locate the positions of the images in space as seen under various conditions of diplopia one needs bear in mind the laws of projection and the laws of direction. Briefly, the underlying physical and physiological facts are:—(a) The image of an object formed upon the retina above the fovea is projected into space downward; objects situated below the horizontal visual line are recognized by that portion of the retina above the fovea: (b) the image of an object formed upon the retina below the fovea is projected upward: (c) the image of an object placed upon the retina to the nasal side of the fovea is projected toward the temporal side and (d) images formed on the temporal side of the fovea are projected toward the nasal side.

407. In homonymous diplopia the right image belongs to the right eye and the left image to the left eye. It is caused by an inward deviation of the eye as in esotropia. Fig. 205 shows the right eye (O. D.) fixing upon the object *F*, while the left eye (O. S.) is turned inward so that rays from *F* fall upon its retina to the nasal side of the fovea and are projected outward to the temporal side: the result is that the left eye sees a false object to the left of the real object. The right eye, as shown in the figure, fixes the point *F* which forms

its image at the center of the yellow spot, M_1, while the left eye, due to its excess of convergence, fixes the point f_1 which forms its image at the center of the fovea, whereas the point F forms its image at a point on the retina which is situated to the nasal side of the fovea at E. Let us give the left eye its relatively correct position by rotating it about A so that its visual axis, M_2Af_1, may take the direction M_2AF. In this new position, in order that an image may be produced at E, the point f_2 must be situated at a distance to the left of F equal to

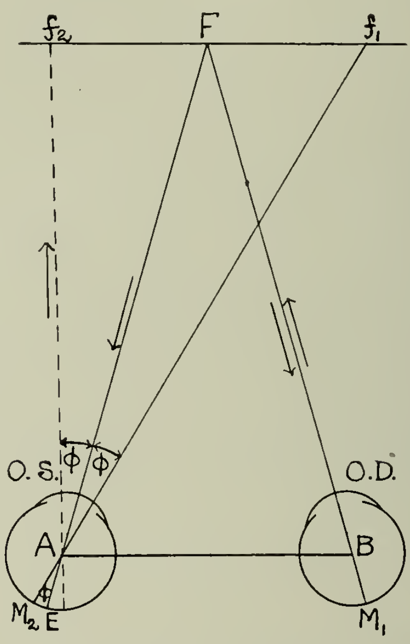


Fig. 205.—Illustrating the Phenomena of Diplopia.

the distance of f_1 to the right. This demonstration shows, in reality, that the left eye, deviated inwards by an amount represented by the angle Φ, projects its image of the point F outwards to f_2 such that the direction of projection forms with the line FE an angle equal to the angle of deviation Φ. We can so arrange matters by the use of prisms as to give the ray FE a direction such that it will coincide with the fovea M_2. A prism placed base *out* before the left eye will deviate the light toward its base and therefore so displace the ray within the dioptric apparatus of the eye as to place it upon the fovea and the image will then be projected to F and the diplopia disappear. In

other words, the prism must give to the incident ray a deviation equal to the angle Φ, which is the angle of deviation of the left eye.

408. In heteronymous diplopia the right eye, for example, may fix the object and the left eye turn outward or exhibit a condition of exotropia. In this case the rays from the object fall upon the retina of the left eye to the temporal side of the fovea and are projected outward in space to the nasal side with the result that the left eye sees a false image to the right of the real object. This condition of affairs is often referred to as "crossed" diplopia.

409. At the risk of too much repetition at this point (for the writer has found that students and practitioners are too often at a loss as to the correct interpretation of these physiologic ocular phenomena) let us apply these principles to the location of images in cases of the deviation of the images in a vertical direction. Let it be first sup-

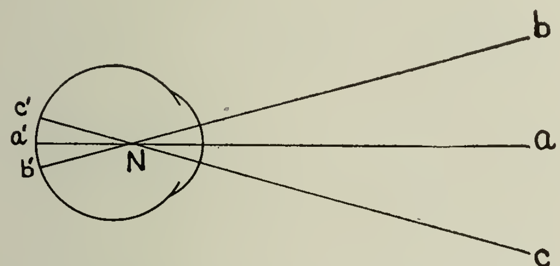


Fig. 206.—Optical Principles Involved in the Various Positions of the Eye and Images of a Given Object in Space.

posed that the images of objects fall upon the retina of a single eye. Let the objects, b and c in Fig. 206, be at the same height, one above and one below the line of primary fixation. Let a be the point of fixation. The image of b, the upper object, is then received at b' which is below the macula and the image of c, the lower object, is perceived by a point on the retina, c', which is above the fovea. Hence, if an image is impressed at a point in the retina which is above the point at which another image is received, that which forms its impression above is mentally interpreted as being below and the object is, in the judgment of the observer, located at a point below the other object. According to the law of corresponding points the point c' in one retina will be removed in the vertical meridian of the retina as far upward as its corresponding point in the other retina. If the distance bc is represented by the distance $b'c'$ on the retina, then if two images are received upon the retinæ, the distances of b' and c' from the macula on the lower quadrant of one eye would equal the

distance from b' and c' from the macula in the lower quadrant of the other eye. Applying these principles, let O in Fig. 207, be an object seen by both eyes. If one eye, say the right, fixes the object the image will be perceived at the macula m_1. Let the left eye deviate downward. Then the image of O will not be produced at m_2 but at n, since the macula m_2 will have been rotated upward and the incident ray from O passing through the nodal point will meet the retina at the point n below the fovea. Accordingly, the image of O perceived at the retina at n will be mentally located and judged in space as at O', not below the object O but at a distance above O equal to the angle of deviation Φ.

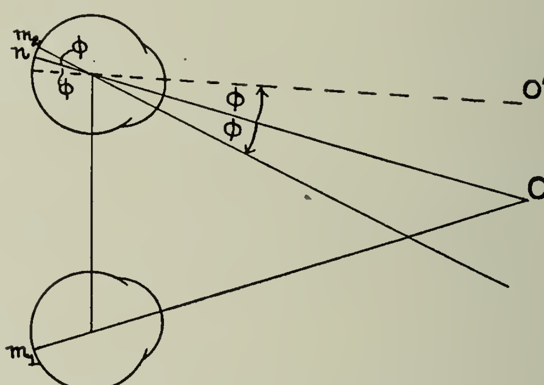


Fig. 207.—Illustrating the Optical and Visual Phenomena Involved in Homonymous Diplopia.

410. Binocular vision depends upon the blending or fusion of the images formed in each eye and the natural desire to preserve it is the origin of the impulse which directs the movements of the eyes and keeps them in association in the same direction. The subject of *strabismus,* therefore, not being able to readjust the nerve associations *assigns such position to the object of vision as an object stimulating the same part of the retina would have if perceived through an eye in its normal position. The displacement of the false image is always in the direction opposite to that of the false position of the eye.* This is certainly a correct rule fitting the majority of cases and we have used the word "always" in the above sentence with the one reservation that there are a very few anomalous conditions in which false interpretations arise from its application. It occasionally happens that a person having a divergent strabismus will, when caused to recognize his diplopia, insist that he sees the image homonymously and

again, when a convergent strabismus is present, he may describe the positions of the images as crossed as though the phenomena arose from a divergent condition. These phenomena are perplexing especially when there is a small convergence or divergence of the axes of the two eyes. Stevens claims that the anomaly presents itself only in cases in which there is not only the lateral but also a distinct vertical deviation as well as an extreme declination and as a general rule, to which there are a few exceptions, is observed after an operation for the correction of the lateral deviation in which the difference of height of the images or the extreme declination has been ignored.

411. Since a prism interposed between an eye and the point of fixation changes the path of the light which enters the eye from this point it is apparent that if, during binocular fixation, we place a prism before one eye, the light which then enters does not fall upon

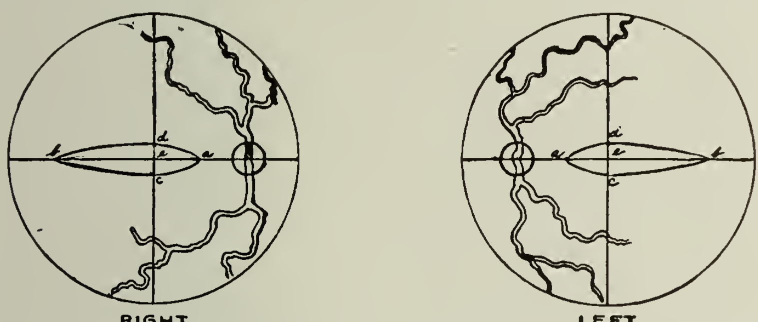


Fig. 208.—Field of Binocular Fusion in Each Retina. (After Savage.)

the macula of this eye and in consequence of this diplopia would result. But our natural and normal desire to avoid diplopia is so great that, in so far as the eye (or perhaps more accurately the eyes, since the innervation would be delivered to the muscles of both eyes engaged in the conjugate act of preserving single vision) is able to do so, it quickly readjusts its position and assumes that direction which causes the image to fall upon the macula. The strongest prism, with fixation at twenty or more feet, which can thus be overcome in the accomplishment of binocular vision measures the *breadth of fusion*. This *fusion power* varies greatly in different directions and, the same direction being considered, varies greatly with the individual and may be "sthenic" (or in strength) or "asthenic." The field of binocular fusion can be determined only by the use of prisms; it is necessary to determine the powers only in the four cardinal directions. The accompanying cut, Fig. 208, due to Savage, shows approximately the shape

and size of this field of fusion. When an image is displaced by a prism to any point within this field, while the image in the other eye is on the macula, an effort at fusion will be made and if the muscle which is called into play, or the innervation, is strong enough, fusion will occur at once. When the image is thrown, however, by a sufficiently strong prism outside of the field of fusion, the "guiding sensation," as it has been so fitting called by Savage, which seems to reside in this area only, will not call on any muscle to move the eye for purposes of fusion. The power of the recti muscles for fusing images, taken as an average and expressed in prism degrees, is, for the internus (adduction, tested by prisms base *out*) 25°; for the externus (abduction, tested by prisms placed base *in*) about 6° to 8°; for the superior rectus (superduction, tested by prisms placed base *down*) 3°, and for the inferior rectus (subduction, tested by prisms base *up*) 2° to 3°. *Muscles having normal fusion powers should also possess normal verting powers:* when the one is abnormal the other is likely to be so also. The extent of these versions or rotations differ slightly amongst various authors: Stevens places the standard as follows: *out*, 48° to 53°; *in*, 48° to 53°; *down*, 50° and *up* 33°.

412. *Ocular palsies.* While a detailed description of the various ocular palsies and their diagnosis is not a subject to be dealt with in an article of this kind, a brief description is in order, however, to differentially indicate the variations between ordinary *squint* and *palsy* of an ocular muscle. The term *paralysis* is used to indicate a loss of power in one or more of the ocular muscles and should be regarded, not as a disease in and of itself, but as a *symptom* indicating lesions which may lie in the orbit or in some portions of the optic tract or brain. The symptoms produced by ocular paralysis may be listed as:

(1) *Diplopia.* This is usually the first symptom of which the patient is conscious. Two objects are seen because the images cannot be formed on corresponding points of the retina of each eye.

(2) *Impaired vision.* If the paralysis is slight there may be no real diplopia but simply an overlapping of the two images causing indistinct vision.

(3) *Vertigo.* This is largely due to faulty projection.

(4) *Impaired movements.* There is a noticeable inability of the eye to move in the direction of the paralyzed muscle, as shown when a test object is moved towards this side. The normal eye easily follows the movement, while the affected eye cannot turn beyond the median plane. The secondary deviation of the sound eye exceeds the primary deviation of the affected eye. When the good eye is covered by the

hand or with a screen it becomes the squinting eye and the uncovered eye is compelled to take up the work of fixation; the strabismus is thus transferred from the affected eye to the sound eye.

(5) *Vicarious inclination of the head.* In order to supply the function of the inactive ocular muscle the head may be turned in such a way as to cause the true and false images to be fused into one. When

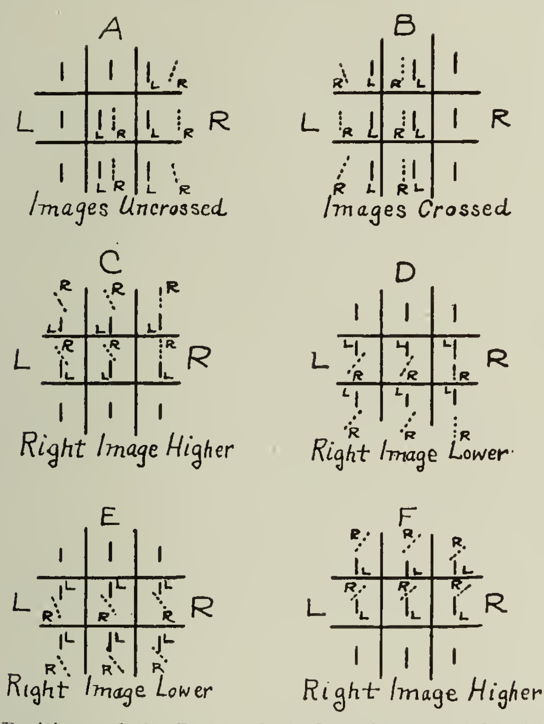


Fig. 209.—Positions of the Images in Palsy of the Individual Muscles of the Right Eye. A, Right external rectus; B, right internal rectus; C, right superior rectus; D, right inferior rectus; E, right superior oblique; F, right inferior oblique.

the eyes turn in the direction of the paralyzed muscle, diplopia is manifest and to avoid this the individual turns his head in the same direction. For example, in paralysis of the right externus or left internus, the face turns to the right.

413. Two points in general stand out pre-eminently in ocular palsies:—*(1) the displacement of the false image always corresponds to the direction of the normal action of the paralyzed muscle,* for a paralysis is followed by a turning of the eyeball opposite to that of the normal muscular action and we know that a false image is dis-

placed in a direction opposite to the turning of the eye; and, *(2) the patient's head turns toward the field of action of, or in the direction of, the paralyzed muscle.*

414. In making the diagnosis as to the seat of the paralysis, the main points to be carefully noted are: (1) whether the false image is seen with the right or with the left eye; (2) whether the diplopia is homonymous or heteronymous; (3) whether the two images are

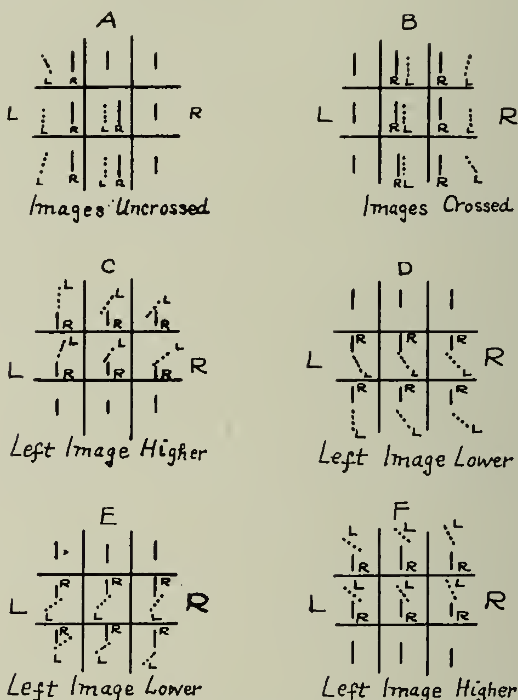


Fig. 210.—Position of the Images in Palsy of the Individual Muscles of the Left Eye. A, Left external rectus; B, left internal rectus; C, left superior rectus; D, left inferior rectus; E, right superior oblique; F, right inferior oblique.

parallel or obliquely inclined; (4) whether the two images are on a level or one higher than the other; in the latter case, whether the true or false image is the higher; and (5) the effect of varying the direction of gaze upon the lateral and vertical displacements and upon the obliquity. By careful study of these features in connection with the study of the physiological action of the ocular muscles and of the result of their paralysis a proper diagnosis may be reached. This procedure seems simple, yet the diagnosis of oculo-muscular paralysis is in many cases a very difficult task, for the reason that the test upon

which most dependence must be placed is that of diplopia and even highly intelligent persons err in describing these unfamiliar visual sensations.

415. The diagrams presented in Figs. 209 and 210, taken from the work of Hansell and Reber on *"Ocular Muscles,"* are plots indicating the nature and the positions of the images seen under diplopia in various portions of the binocular visual field.

416. *Concomitant strabismus.* There are two forms of strabismus: *paralytic* strabismus which, as we have just seen, is due to a paralysis of one or more muscles, and *concomitant,* which, in a great majority of cases, is due to a defect of innervation. The differential diagnostic signs between these two forms of strabismus are well known: in cases of paralytic strabismus the excursion of the eye is less on the side of the paralyzed muscle and the secondary deviation is greater than the primary. In concomitant strabismus the deviation is the same for all directions which the line of regard may assume, although generally the convergence is more pronounced for the downward than the upward look. The patient does not complain of diplopia, but this condition may be artificially produced by any of the well-known dissociation tests dependent upon the displacement of one image, distortion of one image and those which neither displace nor distort, such as the cover test or the parallax test. The distance between the two images when diplopia is thus produced is the same everywhere; the squinting eye accompanies the straight eye in all its movements. Since both eyes cannot be turned toward the same point it is evident that only one eye can fix the object while the other must deviate. Naturally the patient gives preference to the eye with better vision, which then becomes the fixing eye, and the eye with the poorer vision becomes the deviating eye. But this does not mean that the strabismus is associated with one eye any more than with the other; each eye alone is normal as regards its muscular movements as a general rule, but when the two eyes attempt to act together strabismus occurs because there is not a satisfactory co-ordination.

There are three varieties of strabismus, namely: (1) *esotropia* (internal squint, concomitant convergent squint), (2) *exotropia* (external squint, concomitant divergent squint) and (3) *hypertropia* (vertical squint, up or down, and of the right or left eye). To these three commonly named we should add a fourth or (4) *cyclotropia.*

417. When from any cause the eyes tend to assume a degree of convergence greater than that required by the position of the point of fixation, an abnormal tax is placed upon the nervous system in order to maintain the visual lines in the proper directions for binocular

vision. If the tendency to excessive convergence is considerable, the great and continuous drain results in nervous exhaustion and beyond a certain limit of time the effort for binocular vision cannot be maintained. The *latent condition of esophoria* then gives place to a manifest error, *esotropia,* and the true vision is performed by one eye while its mate deviates inward. Latent excess of convergence may then become converted into *manifest* strabismus at times as when, for instance, the eyes are tired from excessive use and particularly in near vision, when spasm of convergence is frequently produced through the association with accommodation. In such cases the strabismus is *intermittent.* But when the effort necessary to give binocular vision is great, or when the fusion impulse is weak it usually happens that the person will abandon the effort to maintain proper convergence and will resort to monocular seeing. The strabismus then becomes constant or *permanent.* This condition usually arises in childhood, for convergent strabismus nearly always develops in childhood. If the vision is equally good in both eyes, either eye may be used for fixation while the other squints. This is known as *alternating* strabismus. But, in general, in strabismus one eye will have the preference over the other and fixation will be performed with the better eye. Although the strabismus is thus apparently confined to one eye it is not a uniocular affection. The excessive convergence is effected by innervation of both internal recti; but in order that the visual line of the fixing eye may be properly directed, adduction of this eye is prevented by suitable innervation of the externus, just as when convergence is maintained together with a lateral deviation of the two eyes (Landolt). In recently formed concomitant strabismus there is no abnormal limitation of the field of fixation in any direction, but when, from continued overaction, the interni have become (in effect) shortened while the externi have become weakened the power of abversion falls appreciably below that of the normal eye.

418. *Deficiency of convergence* is either *latent* or *manifest,* constituting respectively *exophoria* or *divergent strabismus.* As in excess of convergence, so in its deficiency, we find that binocular vision may give place to strabismus with monocular vision only at certain times (intermittent divergent strabismus). If vision is equally good in the two eyes, either eye may be used for fixation while the other squints (alternate divergent strabismus). But if, as is usually the case, the vision of one eye is inferior to that of the other the strabismus will be confined permanently to the inferior eye.

419. *Hypertropia.* In convergent strabismus of high degree there is ordinarily found in addition an upward tendency or deviation of the

squinting eye, while divergent strabismus is usually complicated with downward deviation. Aside from such cases non-paralytic imbalance is not common. Hypertropia, it is claimed by some, while generally considered with comitant errors, is in reality almost always of paralytic origin. Concomitant hyperphoria, or tendency to deviation upwards or downwards with respect to the primary isogonal circle, is quite common and is usually of a low amount, 1△ to 2△. Stevens believes that this form of strabismus (hypertropia), which has been regarded as rare, is in fact the most common of all forms. One may be subject to a degree of vertical squint which is sufficient to prevent the possibility of binocular vision and to result in a high degree of amblyopia while the defect does not attract attention. The defect shows mostly when the patient is looking at a considerable distance, but in many cases it manifests itself by an outward or inward squint when the hypertropic person looks at a near point. Stevens says: "In all cases in which a converging squint, not observable when the patient looks at a distance, occurs when he looks at a near object, either an actual vertical squint or at least a high degree of hyperphoria exists." This author also gives statistics to show that hypertropia occurs as the principal element of squint in about 25 per cent. of all the cases of strabismus (200 in number) which he records. It is more commonly accepted, however, that a true vertical deviation of one visual axis above the other is not often encountered but is usually associated with either esotropia or exotropia. The ciliary overaction in hyperopia often gives rise to a temporary esophoria or hyperphoria which may, under certain conditions, be carried over from heterophoric to heterotropic phases. Anatropia and catatropia are also explicable on this basis, for anatropia may be considered an overaction phenomenon and that in all probability it is closely related to esotropia. The excessive impulse which the ciliary muscle receives in hyperopia in the interests of accommodation also affects the remaining muscles supplied by the third nerve in consequence of which the eyes tend in the directions resulting from a combined action of those muscles, which is up and in. On the other hand, the absence of impulse to the ciliary muscle of myopes carries with it a diminished impulse to the other muscles innervated through the third nerve and their resultant inaction permits the eyes to be deviated in the direction resulting from the combined action of the remaining ocular muscles, the external rectus and superior oblique, which direction is down and out.

420. *Cyclotropia.* This is an actual loss of parallelism between the vertical axes of the eyes and the fixed median plane of the head. This condition probably never exists alone and is usually found in connec-

tion with other forms of heterotropia. There are two classes of cyclotropia known as *similar* and *dissimilar*. In the former the cyclotropia is plus or minus in both eyes, while in the latter class the error is plus in one eye and minus in the other. Savage has termed the first class "non-parallel cyclotropia," i. e., the vertical axes are either divergent or convergent; the latter class he has called "parallel cyclotropia" since the vertical axes are inclined one toward and one away from the median plane. Cyclotropia, like other forms of heterotropia, is alternating; i. e., the fixing eye will have its vertical axis parallel with the median plane of the head, while the vertical axis of the other eye will be torted in or out. It is also comitant, the angle being the same in all positions. Cyclotropia caused by paralysis or paresis and operation is non-comitant and is attended by very annoying symptoms.

421. *Causes of squint.* The causes of squint are many and varied. The chief causes, however, are (1) ametropia, which may produce a change in the normal relationship between accommodation and convergence: (2) amblyopia or impaired vision as evidenced by the number of strabismi that follow amblyopia and opacities of the cornea and of any of the refracting media: (3) anatomic anomalies, such as variations in the interpupillary distance, in the shape of the eyeball and in the divergence of the orbits and (4) mechanical anomalies, such as a difference in the length and strength of the several extra-ocular muscles.

422. The etiology of concomitant strabismus is a complex question upon which there are many differences of opinion. Boehm discussed the relation which exists between hyperopia and convergent squint. Donders, in his classic, portrayed the part that the anomalies of refraction exert in the etiology of squint. When an emmetrope fixes a near point the primary demand which regulates the position of his eyes is the necessity of seeing it single. If one eye is covered this necessity no longer exists, yet the observed person generally continues to converge toward the point fixed due to the relationship between accommodation and convergence. Even in cases of myopia in which, for example, no accommodation is demanded in fixing a specified point, the covered eye will converge somewhat, at least, for the object. This is due to what Hansen-Grut termed *sensation of distance;* for the patient, knowing that the object is a short distance away, converges because he is accustomed to do so in the interest of binocular vision even in cases in which this demand no longer exists.

423. Ametropia produces a change in the normal relationship between accommodation and convergence. While it is possible for accommodation to take place without convergence, or convergence

without accommodation, yet there is a relationship between the two processes which, if materially interfered with, will produce diplopia and ultimately squint. Thus in relative hyperopia it is known that the accommodative effort is accompanied by contraction of the internal recti muscles, or convergence. In a hyerope of, say, four diopters accommodating for infinity, convergence would be stimulated to a proportionate degree at the same time. If such a pair of eyes is accommodating for a near point, this hyperope must accommodate (and would thereby also converge) just that much in excess of what standard eyes would do. The result is that a person with a hyperopia of any considerable amount frequently squints inward in the effort to maintain binocular vision. If, again, one eye is more hyperopic than the other the difficulty of adjusting convergence and accommodation is increased. If one eye is hyperopic by three diopters while its mate has five diopters of error, then six diopters of accommodation is exerted to fix at thirteen inches. The eye having five diopters of hyperopia has, then, at the ordinary reading point two diopters of its error uncompensated with the result that the retinal image of that eye is not clear and accommodation is still further taxed, stimulating at the same time the internus, so that this eye deviates inward and may finally remain convergent. We thus see why a hyperope may become strabismic: it is not as easy to plausibly explain why the great majority of hyperopes do not squint. However, the amount of hyperopia is commonly the same in both eyes and there is apparently developed through habit the ability to accommodate without converging in a proportionate degree.

Myopic eyes, in contradistinction to hyperopic conditions, cannot accommodate beyond their far points but must converge for all points inside infinity. If the myopia is one of six diopters, then these eyes would have to converge six meter-angles to fix an object at that distance (7 inches) without any demand upon the accommodative mechanism. To converge this amount places a considerable burden upon the internal recti muscles; this force and effort cannot be maintained for any length of time without discomfort. The result is that convergence is relaxed and, one eye remaining fixed, the other is turned outward. This is more likely to occur if one eye is more myopic than the other. This explains the presence of divergent squint in cases of myopia: we may with safety say that one of the factors (accommodation) which sustains convergence is wanting. But all myopic eyes do not necessarily have squint as some of them have roomy orbits, strong internal recti and in many cases short interpupillary distances.

424. These are the commonly accepted views. The researches of von

Graefe, Worth, Howe and Maddox suggest, however, another and, to the writer, more satisfactory explanation of these phenomena. For convergence may be differentiated as *tonic, accommodative* and *reflex* or *fusional*. These are diagrammatically represented in Fig. 211 (due to Maddox), in which the eyes are fixing a point O at a distance of a quarter of a meter. In the figure, two lines marked R, R indicate the supposed position of the visual axes were all nervous impulse abolished.

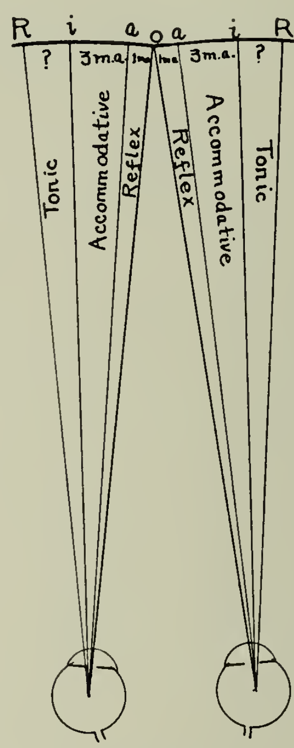


Fig. 211.—The Three Grades of Convergence in Vision at Twenty-five Centimeters. (After Maddox.)

The lines i, i indicate the *tonic convergence* during waking hours, due partially to muscular tone and partially to involuntary tonic action of the converging innervation. The ocular muscles no doubt possess a physiological tone; in addition to this common muscular tone there is a persistent activity of the converging influence, since all experimentation indicates that, if all innervations to an eye cease, the anatomical position of rest of the eyes is undoubtedly one of slight divergence. The visual axes of a pair of eyes are thus brought to the positions i, i

by tonic convergence; *it is the tonic convergence which is tested when von Graefe's equilibrium test at distance or any of the various phorometer, double prism or Maddox rod tests are applied.* For, exophoria in distant vision indicates a deficiency and esophoria an excess of *tonic convergence* and the aberration is corrected, when both eyes are in use, by *reflex convergence* or *divergence* as the case may be. In *distant binocular vision* there are normally only two grades of convergence, the tonic and the fusional.

425. In *near vision* there is, however, what we have referred to as *accommodative convergence.* This second grade of convergence is added, of course, to the tonic convergence and depends necessarily upon the amount of accommodation in action. The investigations of von Graefe, supplemented by those of Howe, Worth, Maddox and others, have demonstrated that when, by means of prisms base up and down before each eye respectively or by means of a double prism *fusional convergence is eliminated* and the tests are made at relatively near points, we have a simple method of measuring the correlation between accommodation and its associated (hence properly called, *accommodative*) convergence. In other words, these tests make fusion passive and hence give a means of determining the convergence normally associated with the accommodation. As a rule, according to Maddox, each diopter of accommodation is accompanied by about three-quarters of a meter-angle of associated convergence. Hence, in a typical emmetrope, not presbyopic, the four diopters of accommodation in vogue for vision at a quarter of a meter are accompanied by three meter-angles of convergence, leaving a deficit of one meter-angle (approximately $6\triangle$) to be made up *reflexly* or *fusionally* as shown in Fig. 211. There is usually an exophoria at thirteen inches of about one (binocular) meter-angle and hence about 4°, but this varies in values assigned it up to 6° to 8°. This exophoria exhibited normally in near vision when the tests are made so that accommodation is active but fixation (involving fusional convergence) is passive is usually referred to as *physiological exophoria.* It is of necessity difficult to assign an exact limit between the physiological and the pathological and each case must be taken on its own merits, for this accommodative convergence test is but one of the many required to ultimately determine the lenticular assistance demanded in any case. Any cause which renders the ciliary muscle less responsive to its motor impulses thereby necessitates increased impulse to accommodation and with it an increase proportionately of the accommodative convergence. When, for example, the object fixed is brought near the punctum proximum of accommodation, the accommodative effort becomes so much greater than

the actual effect produced in the lenticular changes that the associated convergence exceeds its normal proportions and produces an esophoria. In hypermetropia, then, the accommodative convergence without a correction of the refractive error is greater than in emmetropia as a rule. Any condition, however, which renders accommodation easier, so that work is done with less effort, lessens the accommodative convergence. Myopia renders accommodation unnecessary in vision beyond the far point. There results, therefore, a diminution of accommodative convergence. Numerous experiments demonstrate that convergence is not affected by the actual accommodation produced but by the accommodative impulse in any case. (Some of these points are dealt with in a series of articles by J. C. Eberhardt on "The Dynamics and Economics of the Binocular Functions" appearing in the *Optical Journal* and *Review* 1916-17; also in a series of papers by Charles Sheard on "Dynamic Skiametry and Other Dynamic Methods for the Determination of the Co-ordination of Accommodation and Convergence," *The Keystone Magazine of Optics.*)

426. Reference has already been made to the third grade of convergence known as *fusional* or *reflex convergence.* This is the element which is, without doubt, most affected by ocular fatigue as is well illustrated in cases of periodic squint. There is generally no squint on arising in the morning but as the eyes tire the squint appears. Its manifestation is due in part to the diminishing strength, through fatigue, of the reflex muscular actions. When the amplitude of the visual reflex becomes smaller than the squint the latter cannot be overcome. Such cases as these must not be confused with "accommodative squints" in which the hyperopia may be absolute, or cases in which the squint appears only in near vision when accommodative effort becomes disproportionate to the actual work accomplished. In the preceding paragraphs reference has been made to the tonic and accommodative convergences. We have seen that the tonic convergence is measured by prisms when the tests are made at twenty or more feet and that the findings indicate, in general, the amount of "muscular insufficiency" existing when the eyes are allowed to assume their positions of monocular equilibrium. In binocular vision this excess or deficiency must be innervationally supplied in order to parallel the visual axes at twenty feet. Under standard conditions there is a slight deficiency which is supplied through positive fusion convergence. In turn, at near points, some device must be employed for measuring the accommodative convergence. Fig. 212 shows a simple method for obtaining such data. The test card, bearing a dot and a printed line of type, is usually held at the reading distance of thirteen inches. By

means of a double prism before one eye, its mate being uncovered, three dots and rows of printed letters will be seen: the upper and lower belong to the eye wearing the double prism while the middle line is seen by the eye under test. Let us assume that the right eye is under test. Then, if accommodation and accommodative convergence are associated in the ratio of approximately 2.25 or 2.5 to 1 instead of the commonly assumed orthophoric condition of 3 to 1, the dots and

● **Kindly read these words with care**

Fig. 212.—Dot and Line Test Object in Use in the Accommodative Convergence Test.

lines will appear as shown in Fig. 213 when the double prism is before the left eye. Some 4△ to 6△, base *in,* will be normally required to bring all these dots in a vertical line and the accommodation and its associated convergence would therefor be considered as properly correlated. Should the dots appear initially to be in a vertical line the interpretation would be that excessive accommodative *effort* (not excessive actual result, however) was demanded at the point for which the test was made, since the accommodative convergence was excessive.

● **Kindly read these words with care**

● **Kindly read these words with care**

● **Kindly read these words with care**

Fig. 213.—Images as Seen Under Fusional Dissociation Using the Maddox Double Prism.

The line of type is added beside the dot in order to assure that accommodation is taking place, the patient being requested to read it while the position of the middle dot is being located.

427. There is, therefore, under standard conditions under dissociation tests an exophoria or divergency at near points. This divergence does not exist in ordinary binocular vision since it is overcome or supplied by the fusion reflex which thus prevents doubleness of vision: the exophoria revealed by this test shows that the association of convergence with accommodation is not complete centrally but that a supplementary action is normally needed to supply the deficiency and fuse the two images. The fusion function is maintained in operation by the desire of the cerebral center to keep singleness of the two images.

The sensitiveness of this mechanism can be appreciated when we remember that if double images are produced artificially or through disease it is impossible for the mind to tell whether convergence should be positively or negatively increased in order to bring the two images together. Such an action, of this rather complex nature, must be in general more fatiguing than the mere overflow of one impulse into another. Fusion convergence must, therefore, involve a greater waste of nervous energy demanded for coördination than does accommodative convergence, for the latter is associated with the act of accommodation while the fusion convergence is a separate and independent function. Overtaxation of the reflex convergence may cause many of the complaints listed under the name of "muscular asthenopia," for it is

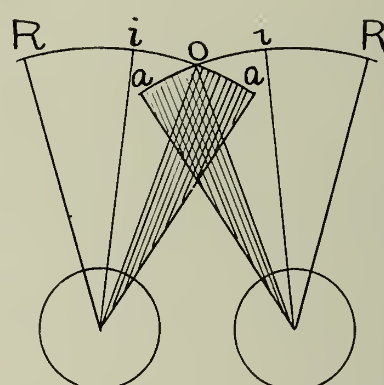


Fig. 214.—Representative of a Case of True Periodic Squint in its Latent Phase. (After Maddox.)

probable that many of these do not involve muscular elements but are, rather, central asthenopias.

428. Fig. 214 attempts diagrammatically to represent the relations between tonic, accommodative and fusion convergences in a case of periodic convergent strabismus. The first two kinds of convergence might be excessive if the subject were hyperopic and would bring the visual axes to *a, a* (over-convergence) instead of to *O,* the point under fixation. The visual axes will, however, be brought back to the point *O,* when possible, by negative or diverging fusion convergence. When, however, the negative reflex convergence becomes fatigued, squint will occur and that particularly at near points. If the hyperopia is corrected the accommodative convergence will be lessened, the tonic convergence will slowly tend to become less and the diverging centers will no longer be forced to function abnormally because of the abnormally

large accommodative innervation and associated accommodative convergence. Squints (high phorias) are thus often relieved and approximately normal convergence and accommodation relations established by the wearing of proper lenses. The effects of tenotomy in such cases are somewhat different; the anatomical divergence is increased and this thereby compensates and offsets the excessive tonic and accommodative convergences.

In cases of myopia, in which exophoria exists in both distant and near vision, an analysis similar to that which we have given above will show that the amount of positive fusion convergence demanded at near points is generally excessively large. The drain is therefore upon the positive fusional innervation; if this is unable to bear the load efforts to maintain binocular vision may cease and divergent strabismus ensue. When, however, the myopia is corrected, in part or in whole, accommodation is made active and the positive convergence associated with accommodation then enters as a factor to aid in the relief of the burden carried by the fusion convergence.

429. These analyses give a logical basis for the explanation of *why* all hyperopes do not have convergent squint and all myopes do not have divergent squint. For strabismus will not occur when the amount of either positive or negative fusion convergence demanded can be supplied and leave in addition an adequate reserve. The whole of the convergence is not supplied through the innervation associated with accommodation but the deficit is made up where possible through reflex convergence. Assume, for illustration, a case of myopia of 3 D. with an exophoria of 3△ at distance. Assume further an interpupillary distance of 64 mms. and that fixation is at 13 inches. A simple calculation shows that 20△ of convergence is demanded for fixation at this point: of this amount the convergence associated with accommodation furnishes nothing since the accommodation is nil. The fusion convergence must, therefore, under the conditions assumed, supply about 23△ of positive convergence in order to compensate for the losses occasioned by the tonic, accommodative and normally demanded fusional convergences. The whole responsibility for binocular vision is thrown in large measure upon the fusional centers and these may be unable to comfortably supply the demand and divergent strabismus therefore develops. If, again, we assume that the full error is corrected and hence 3 D. of accommodation demanded and produced at the near fixation point, then approximately 13△ of the convergence ought to be supplied through the accommodative convergence and leave but 10△ to be cared for through the medium of reflex convergence.

430. We have mentioned *amblyopia* as one of the possible causes

of squint. Statistics show that from 30 to 70 per cent. of all squinting eyes are amblyopic. Congenital amblyopia, due to imperfect development, doubtless plays an important part in many cases of squint: the cones of the fovea, the optic nerve or the visual centers in the brain may be at fault. This form of amblyopia is to be distinguished from that which is due to disuse and to the habitual suppression of the images in one eye known as amblyopia ex anopsia. Worth in his "*Squint*" says that congenital amblyopiæ exhibit certain peculiarities in common. He cites amongst others the following salient points: the fundus and media are normal in appearance; the fields of vision, both for white and for colors, are full; the peripheral form vision is normal up to within 20° of the fixation point so that "the defect would seem to consist in a want of due preponderance of the macular region and not in a general lowering of the sensibility of the visual apparatus." Worth found no case in which the vision of the amblyopic eye was less than 6/60. The most remarkable feature of these cases is that the defect is confined to one eye which almost invariably has a high degree of compound hyperopic astigmatism while the other eye has either emmetropic or low hyperopic conditions. In many cases the fusion faculty is well developed, as shown by examinations with the amblyoscope. In amblyopia ex anopsia, however, the blindness often reaches a degree which is never met with in the congenital form. In congenital amblyopia the central vision is never lower than 6/60 (Worth); this is the visual acuity normally found at 5° from the fixation point. In extreme cases of acquired reduction in acuity there is often a scotoma extending about 15° to 20° around the center of the field of vision.

431. These considerations form a logical basis for the determination of cause and effect; the possibility of attributing the strabismus to the amblyopia or the amblyopia to the strabismus is made possible. This is, of course, most important from a prognostic point of view. The "ex anopsia" variety is very clearly demonstrated by the rapid, though generally only partial, recovery of visual acuity which attends occlusion of the better eye. Javal has pointed out that if occlusion be indulged in for a considerable period of time, improvement takes place very often by sudden increases or steps, since the eye is at first not only lacking in acuity but is also awkward in seeing. This takes considerable practice to overcome.

432. Having confirmed what has been said about projection of retinal images and the conditions in muscle paralysis it might be supposed that in concomitant squint there would also be double images—homonymous in convergent and heteronymous in divergent squint. Experience

shows that this is not the case except in conditions of convergent strabismus of myopes, but that the patient does not see at all with the squinting eye the object fixed by the better eye or, in other words, that the retinal image of the squinting eye remains unperceived or suppressed. The squinting eye is not, however, entirely excluded from participation in the visual act. It can be shown that objects within the visual field of the squinting eye are partly seen and partly unseen, or that there is regional exclusion. The squinting eye may perceive everything lying within that part of the total visual field belonging to the squinting eye alone. The individual fields coincide in a smaller area than normal in divergent squint and the total visual field must then be greater than normal; in convergent squint, for the reverse reason, it must be smaller than normal. Objects lying within that portion of the visual field common to both eyes are not necessarily excluded from the squinting eye but only those that disturb the vision of the better eye. Many squinting persons testify that when reading they see double at the beginning or end of a line (i. e., that the image in the squinting eye is not suppressed if it appears on a background of white paper) but that it is not seen, or is suppressed, when it appears at a point where letters are seen by the better eye. Diplopia for objects seen at one side causes, however, little disturbance just as in the case of physiological double images. The fixing eye will conquer when there is a struggle between images of different objects for the same point in space. The nearer normal eye has, on the one hand, a greater visual acuity and, on the other hand, it uses in its assertion of supremacy its most sensitive retinal region while the squinting eye has only eccentric vision from a peripheral and less sensitive retinal area.

433. The *suppression of retinal images* is the means adopted by the eye for freeing itself from the disturbances of diplopia. The process must be a psychical one and wholly unconscious, accomplished by association of action of the two eyes. This can be demonstrated by the fact that the double images which are unnoticed in such cases are usually made perceptible by very simple means. Many who squint can see double as soon as their attention is called to the possibility of there being two images present; others may be made to see double by holding a piece of red glass in front of the better eye; or again a prism may be placed base up or down in front of the directing eye while the colored glass is worn before the better eye. There will then be formed upon the retina of the deviating eye an image of the object fixed by the other eye and this image will fall upon an area where retinal images have not as yet been suppressed because they arose from objects seen peripherally by the better eye also.

434. There also arise phenomena, termed *paradoxical diplopiæ,* discovered by von Graefe. In examining persons in whom convergent strabismus had been partially corrected by a tenotomy, he found crossed diplopia although the visual lines were still convergent and hence all tests should have shown homonymous or uncrossed diplopia. Javal explained these phenomena by saying that there is developed a vicarious fovea. The patient has first to learn to suppress the image in the strabismus eye; there is then gradually formed a notion of the false position of the squinting eye and the patient finally has to learn that an object which forms its image on the fovea of the good eye forms its image at a point inwards from the fovea of the strabismic eye and hence the image is localized at the place where the object to which it belongs is situated. It is, therefore, as if there were developed a correspondence between the vicarious fovea and the fovea of the good eye and such patients, under dissociation tests by means of vertical prisms, will see the two images almost on a vertical line instead of exhibiting widely separated images. If, then, in such cases a tenotomy is performed which does not completely correct the error, the image of the point fixed will be formed somewhere between the true and the vicarious foveæ. Patients first project the image according to the vicarious fovea and therefore see the images heteronymously. Later the true fovea may exert its supremacy and objects will be seen homonymously. It has been found that binocular *triplopia* can arise when, in the course of development of the change of fixation lines, the patient projects the image of the strabismic eye according to both foveæ and thereby sees one object to the right and one to the left of the true image.

XXIV. DIAGNOSIS OF STRABISMUS

435. A few tests for strabismus are briefly indicated below.

(1) *Inspection.* Simple inspection will often not only determine the presence of strabismus but will also locate the fixing eye and show the probable degree of deviation. The appearance of squint may, however, be illusory for myopic eyes frequently give the impression of a slight convergent squint while hyperopic eyes often appear divergent. This is due to the value of the *angle alpha* which, as has been pointed out, differs in value in various ametropic conditions of the eyes.

(2) *Ophthalmoscopic corneal images.* This test consists in reflecting the light, first on one eye and then on the other, from the mirror of an ophthalmoscope held about ten inches from the patient's face. The observer looks through the mirror aperture and directs the patient's gaze to the same aperture. A small circular reflection from the mirror

will then be visible in each eye. In emmetropic eyes the reflection will appear slightly to the inner side of the center of each cornea and if they are symmetrically disposed in the two eyes the existence of squint is made improbable. This method has been dealt with by Maddox in a chapter entitled "Ophthalmoscopic Images" in his work on *The Ocular Muscles.*

(3) *The cover test.* In any case of strabismus, whether manifest or latent, one eye fixes the object and the other deviates. The patient's attention is directed to some distinct distant object. If the fixing eye is occluded the patient is compelled to rotate the deviating eye into the proper position to fix the object. By means of a cover placed in turn before each of the eyes, the observer can watch the movements that occur behind it. If the cornea of either eye makes an excursion inward when its fellow is covered, it must previously have been deviated outward, and if the movement should be outward, the previous deviation must have been inward. Having the patient fix a pencil or other small object at eighteen inches we interpose a card before one eye. If the balance between convergence and accommodation is normal, the covered eye automatically holds its position. If convergence is in excess, the covered eye now having nothing to fix, turns *in* while if it is insufficient it turns *out.* These movements (or their absence) are often too slight to be definitely made out by observations carried out behind the screen. If, however, the covered eye is closely watched and the screen quietly but quickly withdrawn, it will fix the object by a movement of redress.

(4) *Linear strabismometry.* This takes account of the displacement of the pupil by measuring the amount of deviation in millimeters. It was at one time a popular method owing to the accepted theory that a displacement of the pupil of a certain number of millimeters could be rectified by setting back the tendon by an equal number of millimeters. The method is now practically obsolete.

(5) *Hirschberg's method.* A lighted candle is held about one foot in front of the patient's face, the operator placing his own eye near the candle. The operator looks over the flame at the eyes of the patient who, in turn, is told to fix his gaze upon the candle. The position of the corneal reflection in the squinting eye indicates roughly the amount of squint. The breadth of the cornea is about twelve millimeters. A squint which brings the reflection to the edge of the cornea then indicates a displacement of 6 mms. in the image and shows a deviation or squint of 3 mms. According to Hirschberg, if the reflex is at the margin of the pupil (3 mms. in diameter) a strabismus of 12° to 15°

is indicated: a reflex situated half-way between the center of the pupil and the corneal margin represents a strabismus of about 25°.

(6) *Javal's perimetric method.* In this method the patient is seated so as to bring the squinting eye into the center of the perimeter. At a distance of five or six meters a candle or luminous spot is placed for the fixing eye to regard. Another candle or small electric lamp is then moved along the arc of the perimeter, with the operator's eye constantly behind the light, until its reflection appears to occupy the center of the cornea. The squint is then measurable on the perimeter arc.

(7) *Charpentier's perimetric method.* The lamp is placed over the fixation spot of the perimeter and the operator's eye travels along the arc until the reflection appears to lie in the center of the cornea of the squinting eye. The squint is then measured as one-half of the angle of the arc.

(8) *The tangent strabismometer of Maddox.* This is in principle a flattened-out perimeter. The instrument is used by having the patient face the candle at the zero mark of the instrument at a meter's distance while the operator places his own head between the two but a little lower down and about a foot from the patient. The corneal reflections reveal which is the squinting eye and the amount of the squint is guessed at after the manner of Hirschberg's principle. The patient can then be directed to look at various figures upon the strabismometer until the reflection occupies its proper position. Maddox says that this instrument can be used for measuring and determining (a) concomitancy, (b) secondary deviation, (c) angle gamma, (d) degree of eccentric fixation, (e) imperfect duction, (f) vertical elements in the squint.

(9) *Worth's deviometer.* This is essentially a modification of the preceding method and is admirably adapted for testing small children. The instrument consists of an upright piece carrying an arm which can be swung to the right or to the left. On the back of the arm is a scale of tangents to degrees at sixty centimeters distance. Below the zero of the scale is an electric lamp of the cylindrical type. The operator flashes on the light and observes the corneal reflections. The position of the light on the cornea of the squinting eye enables a guess as to its deviation to be made. A brass carrier is then moved out on the horizontal arm; this is tapped with the finger to attract the child's attention. The light is then flashed on; if the line of light on the cornea of the squinting eye is in a corresponding position to that which it formerly occupied in the fixing eye, the angle of squint is read off on the scale on the back of the arm.

(10) *Priestley Smith's tape method.* In a darkened room the observer places himself at a meter from the patient. The patient gazes into distance. Light is then thrown by means of a retinoscopic mirror (or an ophthalmoscopic lamp) on the deviating eye. With the tape measure held at zero at the retinoscope, the observer moves his free hand horizontally away from the direction of the deviating eye, directing the patient to follow his moving hand, through which the tape measure slides, until the deviating eye is brought into such a position that the corneal image rests in the center of the pupil. The tangent relation enables the operator to calculate the angle of squint.

(11) *The diplopia test.* By determining the relation of the image of the squinting eye to that of the fixing eye a diagnosis of the actual position of the squinting eye and its degree of variance from parallelism can often be made. In amblyopia, as previously remarked, the operator will experience great difficulty in forcing a recognition of the image of the amblyopic eye since such a patient does not complain of diplopia nor is he conscious of the false image of any object. The use of prisms, base in or out, before the squinting eye and a colored glass before the other eye in order to render the true light dull and indistinct will often permit of the recognition of two images. The prism power before the squinting eye which permits of a fusion of images is the prismatic measure of the deviation. Another important factor is often brought out by this method, and that is the presence of a vertical difference in level of the two images. The determination of the presence or absence of hypertropia is very necessary.

(12) *The tropometer.* This is a supplementary test and the information furnished by this instrument is of value in showing the exact power of temporal rotation of esotropic eyes, nasal rotation of exotropic eyes and so on.

XXV. TREATMENT OF STRABISMUS

436. The treatment of strabismus may be divided into *operative* and *non-operative.* We shall treat briefly of the latter class only and pass over the operative method with the simple statement that when various methods such as the use of cycloplegics, convex or concave lenses, prisms for relief or exercise, prism exercises and efforts to improve vision, fail to remove the causes of the squint operative measures alone remain and the choice lies between a tenotomy or an advancement.

The non-operative methods of treatment of strabismus involve (1) re-establishment of diplopia, (2) correction of the refractive errors, (3) prisms, (4) cycloplegics, (5) exclusion of the good eye, (6) bar reading, (7) exercises with the stereoscope or amblyoscope, (8) ex-

ercises without the stereoscope. These methods are designated as orthoptic or educative; one or more of them may be used at the same time as the nature of the case seems to demand.

(1) *Re-establishment of diplopia* and of the vision of the strabismic eye should presumably be first attempted when such are not already existent to a fair degree. The non-squinting eye is kept covered by means of a blinder or under the influence of atropine. During this period of treatment the two eyes should not be left uncovered at the same time since the neutralization of error accomplished may disappear and the strabismus may even increase.

(2) *Correction of the refractive errors.* The essential factor (or one of the essential factors at least) which permits an ocular deviation to occur is a defect of the fusion faculty. The eyes, lacking sufficient fusional innervation, are for the time being kept approximately correlated by their motor co-ordinations. They are, however, in a state of unstable equilibrium and are easily persuaded to squint under influences which would have no effect on them ordinarily. In a majority of cases it is the state of the refraction which chiefly determines whether the eyes shall deviate inwards or outwards. Since hyperopia and hyperopic astigmatism demand abnormal accommodation and hence abnormally large associated convergences, it is a rational treatment to give convex lenses (either spheres or cylinders) to the full limit possible. For in such cases these lenses serve a double purpose in that they not only improve vision by correcting the refractive error and thus afford a stimulus to binocular vision but they also lessen the need for accommodation and in so doing diminish the over-convergence and relieve the burden upon the divergent fusional centers. Divergent strabismus, being ordinarily associated with myopia, arises in large measure from the lack of accommodative effort and its associated convergence, thus throwing the burden of positive convergence at near points upon the convergent fusional centers. All myopes under 6 diopters should ordinarily be given a full correction of their optical defects so that accommodation may be normally brought into action, while in cases of myopia of higher degree the fullest possible correction which will afford a fair degree of comfort in work at the near point should be prescribed. Hyperopes having divergent squint should, in general, be given the weakest spherical correction consistent with comfort in near work; presbyopes, if myopes, should be given the strongest minus corrections or, if hyperopes, the weakest plus corrections possible for use at thirteen inches.

With respect to the lens corrections, the important points are: (1) that the spherical correction should be as full as possible (convex

lenses in convergent squint coupled with hyperopia and concave lenses in divergent squint coupled with myopia) and any existing astigmatism be fully corrected, and (2) the lenses should equalize the accommodative action and, as far as possible, the visual acuities of the eyes. This last point brings up for consideration the equalization of accommodation and the obtainance of as nearly equal visual acuity in both eyes as possible. This the writer believes to be a very essential point. Accommodative action, or rather the relief from such action, can be readily accomplished by various methods for twenty feet or infinity. Assume a case of convergent strabismus in which static refraction at 20 feet evidences as the full error O. D. + 4 D. S. and O. S. + 2 D. S. In such a case as this let us further assume that visual acuity and other tests demonstrate that the right eye is the squinting member; likewise, let it be amblyopic and fail to give, let us say, any indication of visual acuity greater than 5/10 wearing the lens which gives the best vision and which approximates in value that determined by skiametric methods. In the case of the left eye we shall say that + 2 D. S. brings 20/20 vision. Tests made upon the accommodation at 13 inches, however, are likely to disclose in such a case some such data as follows: right eye, wearing distance correction, cannot read anything on the near test card but by the addition of + 3 D. S. to the static correction, making + 7 D. S. as the full near-working correction, the patient can read No. 3 or No. 4 Jaeger type with fair ease; for the left eye, however, tests upon the accommodation at thirteen inches, the patient reading No. 2 Jaeger type through concave lenses, demonstrate a total accommodative amplitude of 7 D. Experience has shown that in many cases such as this hypothetical one various occlusion, bar reading and stereoscopic exercises fail to develop a normal relationship between accommodation and convergence and establish normal conditions when the *distance* correction only is prescribed for the amblyopic eye. The writer believes that many such ocular conditions which are often pronounced hopeless would be improved and ultimately saved if the treatment were instituted from the near or reading point rather than from the distance findings only. Certainly accommodation and convergence are normally demanded at fixation points inside of infinity: the accommodative powers must logically, then, be developed and the visual acuity improved before harmonious correlation of the two eyes can take place. This development of accommodative power can be best accomplished at the reading point; since this may have become weakened or partially lost through lack of use it is logical to supply such an eye with such a lenticular correction as will enable it to see as nearly normally as possible at near points and to give it such optical

assistance as will make it a normally functioning, useful organism and stimulate development. As the accommodation, etc., develops, this near correction can be cut down in value until ultimately in many cases nearly (if not full) normal accommodative amplitude will have been restored and the distance correction prove satisfactory for all purposes. The writer believes, therefore, that such cases can be handled to advantage by (1) prescribing full distance corrections for general wear with occlusion of the better eye from time to time for stated periods and (2) by prescribing a pair of glasses for near work in which the amblyopic or weaker eye is given such lenticular assistance as will equalize if possible the apparent accommodative powers and acuities of the two eyes and if this is impossible (as is generally the case) to give such lenses as will afford the poorer eye the best working conditions possible in the hope of developing the accommodation. The patient should then be instructed to cover up the good eye with a blinder and engage in reading coarse print for short periods of time very frequently.

(3) *Prisms* do not correct strabismus: they simply aid in securing binocular vision in spite of the deviation due to the squint by optically producing a deviation of the rays within the eye of such an amount as to produce an image upon corresponding points and thereby re-establish binocular vision. The base of the prism is placed opposite to the ocular deviation; hence, bases *out* in cases of convergent strabismus and bases *in* in cases of divergency. Strictly speaking such optical assistance in no wise corrects the strabismus but leaves the eyes in their positions of weakness. As to the advantages and disadvantages of the use of relieving prisms and the amounts which should be prescribed under various conditions, the reader is referred to the various standard treatises dealing with ocular muscles. We have remarked that, for the cure of squint, prisms are useless. There is one possible exception, however. If diplopia is elicited but the two images are too far apart to be fused and one of these images is faint owing to its position on the retina of the deviating eye, prisms may be employed with profit for the purpose of bringing this image nearer to the macula so that it may become clearer and capable of being fused with the other image. Such prisms must not, of course, cause fusion directly but are simply the indirect cause or instigators of it. They are temporary measures only and should be reduced in strength as the muscles become more nearly balanced in action. In divergent squint prisms base in are much more likely to prove valuable than are prisms bases out in convergent squint.

(4) *Cycloplegics* are employed for the paralysis of accommodation: they are applicable in that large class of cases of convergent strabismus

occurring in young children having hyperopia. By a suspension of the act of accommodation there will be a suspension of the convergence associated with the former. During the continuance of the cycloplegic the lenses which correct the ametropia and of which the strength is as nearly as possible the full correction are worn constantly during waking hours. In many cases of young children the squint begins to decrease as soon as the cycloplegic takes effect and the prognosis is favorable for good vision with glasses when this occurs. In other cases, while the drops are in the eyes and glasses worn constantly, the squint entirely disappears but reappears as soon as the effect of the cycloplegic wears off. In such cases the drops are at present ordinarily put in one eye only and that the good eye. The possessor can then use this eye for distant vision as before, but on account of the abolition of accommodation will not be able to use it for near work. For this purpose he will be compelled to bring into action the squinting eye in which the function of accommodation (whatever power it may have) has not been artificially (i. e., through the use of cycloplegics, et al.) interfered with. In this manner the vision of this eye can be improved under proper optical correction, fixation preserved and amblyopia from disuse avoided.

(5) *Exclusion of the good eye.* This method consists in covering the eye by placing over it a patch or putting before it an opaque lens and thus compelling the patient to use the squinting eye for all visual purposes. This method of treatment has somewhat the same effect as the use of a cycloplegic, but few parents will take the trouble to do this every day and continue the practice for some length of time, and few children are willing to bear the inconvenience. A point of difference between the two methods, however, is that when the eye is simply covered it will still be able to accommodate in sympathy with the uncovered eye. By exclusion of the good eye the inferior or squinting eye preserves the faculty of fixation and develops and increases its vision. In alternating strabismus, where first one eye and then the other is used, each eye is able to maintain its vision and power unimpaired. Nature surely points the way in this decided manner and it seems wisdom, therefore, to follow and to transpose every case of fixed unilateral squint into an artificially created alternating one by exclusion of the good eye for several hours each day and compelling it to assume the squint for that period.

(6) *Bar or controlled reading.* A pencil or ruler is interposed in front of the eyes in a position practically parallel to the printed page which the patient is instructed to read. If he does not possess binocular vision but is making use of one eye only, when the line of vision of this eye comes to the pencil or ruler a certain portion of the

page will be cut off and the patient will be compelled to skip a word or two. If the two eyes are co-ordinated, however, no portion of the print will be occluded and there will be no interruption in the reading. By persistent practice, covering months in many cases, the patient may be taught to use the two eyes together. Considerable effort and patience may be required at first but gradually the function of binocular vision may bcome established. It is only after a considerable time subsequent to the re-establishment of binocular vision that the patient can see stereoscopic relief.

(7) *Exercises with the stereoscope and amblyoscope.* To exercise fusion a stereoscopic box may be employed without prisms but with lenses whose focal length is equal to the depth of the box. Partial pictures are placed in the two sides of the instrument in such a way that the complete image can be obtained only by combining them. At the commencement of these exercises they must be sufficiently near to each other for fusion to occur, after which gradual separation and approximation of the cards serves as a gymnastic exercise. There is, in these cases, no accommodation present and the effect on the muscles is increased if the lenses be gradually lessened in strength to permit of accommodation during the exercise. Instead of moving the card, varying prismatic power can be obtained by altering the distance between the lenses.

The Worth-Black amblyoscope is an ingenious instrument devised for stimulating and exercising the fusion faculty. It consists of two bent tubes through which two pictures are seen and fused. One set of pictures is designed specially for inducing stereoscopic impression, a second for stimulating binocular vision and a third for stimulating fusion. The distances between the pictures can be varied or the angle of convergence or divergence changed in the instrument; the intensity of illumination can also be varied. When there is convergent strabismus in children, the period of life during which an impaired fusion sense can best be remedied is that between three and six years of age (Worth). After the age of six or seven years the fusion faculty may have become too depleted to be restored.

(8) *Ocular exercises.* If harmony between the accommodation, accommodative convergence and fusional convergence is restored by lenses embodying the corrections of the ametropic errors, then the ordinary exercise of convergence and the lateral movements of the eyes usually serve to strengthen weakened muscular functions or to restore relative equality of power between antagonistic muscles. This is natural training; muscle training, frequently called *orthoptic exercising,* consists of exercises for the purpose of strengthening weak

muscles or weakened functions of muscles. Various methods have been recommended by the authorities who deal with this subject, but there is no agreement as to the best method. Probably there is no single superior method, but natural gymnastic exercises, such as in the alternate contraction methods, generally prove the most satisfactory. Likewise, it is true that a great deal depends, in the success of these various exercises, upon the personality and skill of the operator and upon the patience and faithfulness in the carrying out of instructions on the part of the patient. In all cases the refractive corrections are worn during the exercises and the prisms used are *adverse;* that is, the base is toward the more efficient muscles, thus causing increased action on the part of the defective muscles. Hence, for training the internal recti the prisms are bases *out* and for the external recti they are bases *in:* for the right superior or left inferior the right prism is base *down* and the left prism base *up;* for the other vertical muscles the prisms are reversed.

The three classes of exercises are in general differentiated as (a) varied contraction, (b) maintained contraction and (c) alternate contraction exercises.

In sustained contraction exercises adverse prisms are worn continuously for specified periods.

(a) Weak adverse prisms, 1△ to 4△, are given to be worn frequently every day for short periods. The time of wearing is increased slowly until they can be worn without discomfort for an hour. The same procedure is then instituted at the reading point.

(b) Nearly the highest prisms that can be overcome are first used and their power increased little by little so long as diplopia does not occur. They are used daily for a few minutes, with intervals of rest, some two or three times and for distance only.

In *varied contraction exercises* the action of the muscles to be trained is constantly varied.

(a) By means of rotary prisms, the prismatic power is gradually increased to the extent of the power of the inefficient muscles without diplopia ensuing: a few seconds interval is given in order to obtain complete fusion of the images before each increase of power is made.

(b) The internal recti can be exercised by slowly approaching a pencil towards the eyes until the pencil appears double and then slowly removing it and repeating the exercise. The external recti may, in turn, be each separately exercised to excellent advantage according to Thorington by covering one eye and following an object, such as a pencil, held about two feet from the eye, as the object is carried out from the median plane into the field of action of the externus. This

class or kind of exercise may be spoken of as the natural gymnastic method and is probably one of the best.

(c) Change of distance of the object by a change of the distance of the person viewing it while adverse prisms are being worn. An excellent way is to view the object from a near point and then to slowly move away from it, returning towards it again and so on.

In *alternate contraction exercises* there are produced a series of alternate contractions and relaxations of the deficient muscles obtained by the alternate use and non-use of adverse prisms.

(a) A power slightly weaker than the strongest that can be overcome is used: its power is increased slightly and then again reduced by alternately adding to and removing an additional prism. The strength of the first prism and that of the additional prism are gradually augmented. The duration of the exercises is, at the commencement, two to three minutes daily, the period of time being increased as the muscles become stronger.

(b) A distant plane or luminous spot is viewed alternately *without and through* a pair of weak adverse prisms, each for a brief period. This is the essential feature of Savage's rhythmic exercises. The object is first viewed without the prisms for a few seconds (three to five) and then with the prisms for the same period. In the latter case additional action of the defective muscles is obtained. The relaxation of this additional action results from the removal of the prisms. The prismatic power for esophoria is $2\triangle$ increasing to $12\triangle$: for exophoria $1\triangle$ increasing to $4\triangle$: for hyperphoria $\frac{1}{2}\triangle$ increasing to $2\triangle$.

(c) A variation of this last exercise is to alternate distance vision with that at the reading distance, both of them alternately with and without the prisms, each period of fixation to last for about five seconds.

XXVI. HETEROPHORIA OR LATENT SQUINT

437. Latent deviations of the eyes involve the same principles as do the manifest deviations which are recognized as squints. Heterophoria is the condition of muscular imbalance when perfect fusion is maintained only at the expense of extra effort on the part of the relatively weak muscles or weak innervations. Latent deviations are liberated from the superior influence of desire for binocular vision in the dark, or when one is sleepy or abstracted, when the muscles are not under the control of the single vision centers or are, again, made manifest when the vision of the two eyes is dissociated by making single vision impossible or undesirable with prisms in the one case and Maddox rod and so forth in the second case. Suppressed deviation may be demonstrated by the exclusion of one eye or by means of an

artificial diplopia of some sort so as to dissociate the two eyes or by the arrangement of two objects so that each is seen by one eye only. By dissociation of the two eyes is not meant that any of the innervations are made to cease to be conjugate but that the desire for single vision is removed so that the eyes assume their positions of equilibrium. If a strong prism, base down, is held before one eye, everything appears double and the distances between the double images of an object is so great that the cerebral centers concerned make little if any attempt to unite them since such centers are wholly unaccustomed to so great a separation between the images of a single object. The eyes are therefore dissociated and if any latent deviation exists it will show itself by a movement of one image to the right or left of an imaginary vertical line passing through the other.

438. Heterophoria is as common as ametropia and is in fact the common accompaniment of ametropic conditions. But heterophoria of sufficient degree to cause trouble is not as common. In those who suffer from asthenopic symptoms it is found that in a small proportion of cases the trouble is due to heterophoria simply but that, in the majority of cases, it is due to conditions of ametropia coupled with the associated innervational excesses or deficiencies. Latent strabismus may be due to a muscle or group of muscles being too weak or too strong for their antagonists, or to an abnormal position of insertion of tendons whereby a muscle possesses a greater or lesser mechanical advantage than normally, or to a muscle or group of muscles which are abnormally innervated. We are in many cases unable to determine whether the fault lies in the muscles themselves or in their innervations. It is not commonly found, however, that there is a deficiency or excess in the limits of rotation of either eye. The differentiation between muscular or innervational abnormalities must lie, in so far as ophthalmic science has given us a clue, in a determination as to the relation which the versions and ductions bear to each other. Various methods and tests which can be applied as to the accommodation, the convergence as associated with the accommodation, the fusional convergence and the reserve convergence at the reading point, such as have been discussed in outline under the caption *Causes of squint,* demonstrate that a large majority of cases of heterophoria, particularly those in which asthenopic symptoms arise, are due to excessive or deficient innervation. It is probably true that if all investigations upon the muscular equipoise are made at twenty feet only that we are then entitled to conclude simply that the eyes tend to assume certain abnormal relative directions and we are seldom able to analyze the defect further than this by such tests. It is likewise true that within

certain limits suppressed deviations are physiological, for though the accommodating and converging centers are functionally connected in an intimate manner they are not indivisibly one. We have previously pointed out that, when the eyes fix a near object, they converge less than they accommodate with each approach of the object and that, in the light of the latest researches, there is a physiologic exophoria of 3△ to 5△ at the normal reading point. Worth says that "Heterophoria is essentially a defect of motor balance. Squint, on the other hand, is essentially due to a defect of the fusion faculty." This is doubtless a very fair statement of the facts if the ciliary muscle is included in the list of those taking part in the motor balance.

439. The distinctive names which are employed to indicate the direction of the tendencies are: (a) esophoria, or tendency to abnormal convergence of the visual axes, (b) exophoria, or divergent tendency, (c) hyperphoria (or hypophoria) in which one visual axis tends to lie in a higher plane than the other and (d) cyclophoria, or a tendency to abnormal rotation of the eyes around a fore-and-aft axis so that what should be the vertical axis of the eye is no longer parallel to the median plane of the head.

440. *Pseudo-heterophoria*, as it has been termed, arises in cases of uncorrected ametropia and frequently disappears very quickly when appropriate correcting glasses are worn. It seems, therefore, a wise procedure on the part of the practitioner to determine the heterophorias before corrections are applied to the eyes and also while the patient is wearing the exact correction of his ametropia at distance. This will enable the operator the better to form a judgment as to whether or not changes can be made in the interests of the ocular economy by an increase or decrease of the correcting lenses.

441. The symptoms of heterophoria are those of "eye-strain" in general: frontal headaches coming on particularly toward night, pain through the eyes after close observation of objects, pains at the temples, between the brows, over one or the other of the brows: migraine, dizziness (particularly associated with hyperphoria) and so on. Hyperphoria, or a vertical imbalance tendency, is the form of heterophoria which is most likely to cause trouble, for few persons can bear a hyperphoria of more than one degree without inconvenience. Esophoria is said by many to be the least troublesome. This is probably true when the vocation is an out-of-doors one or is of such a nature as to demand distant-seeing largely, but it is probably one of the most aggravating of heterophoric conditions when an excessive amount of near work is engaged in. It is a question in the writer's mind whether or not modern civilization, with its excessive demands upon convergence

and accommodation, will not develop hyperopia with excessive esophoria and premature presbyopia and that there need not be as great a fear of increase in myopia in school children of the oncoming generations as of highly hyperopic and latent strabismic conditions. In other words, it is the experience of a large number of practitioners that esophoria in greater amount at near than at distant points is very common amongst high school and college students and that this esophoria is functional and tied up with an overly innervated but not overly actuating accommodation.

442. *Methods of testing the relative motor balance of the eyes.* The methods which have been discussed in connection with ocular paresis and strabismus are quite largely applicable also to investigations upon latent deviations. Among the best tests are the following:

(a) *The objective screen test.* This is made by having the patient fix a very definite test-object and screening one eye for fully half a minute. Suddenly withdrawing the screen, watch whether the eye makes an instantaneous movement (corrective movement) and if so in what direction. A corrective movement inward indicates a condition of latent divergence or exophoria. The movement of redress is in the direction of the weak muscles or muscle insufficiently energized.

(b) *The subjective screen test.* A sudden screening of the fixing eye makes the object fixed appear to the patient to move as the deviating eye makes a corrective movement in order to take up fixation. Thus, if the right eye be the one first screened and the object fixed moves to the right there is esophoria. Parallax is measured in terms of the prism which causes its abolition.

(c) *Prism tests.* The methods involving dissociation of the eyes by means of prisms base up or down before one eye and strong enough to produce insuperable vertical diplopia or the Maddox double prism have been briefly described in other paragraphs. These methods permit of the measurement of lateral deviations by the amount of prism, base in or out, necessary to bring the various images in a vertical line. The double prism also permits of the measurement of vertical imbalances since the second, or central, dot or light seen by the eye under test may not be geometrically placed half-way between the upper and lower images due to the double prism, and prisms base up or down are required to produce this vertical balance. The optical and physiological principles involved as to the relation between the direction of the deviation of the eye and the direction of projection have been treated under the heading *Diplopia*.

(d) *Glass-rod test.* This single glass rod or high-powered cylinder test does not depend, like the prism tests, on the separation of the

images of an object but on alteration of the shape of one of the images so that it is no longer recognized as in anywise similar to or belonging to the same object. The explanaton of the optical action of such a rod is worthy of comment. When a point of light is seen through a high-powered cylinder it appears as a ribbon of light at right angles to the axis of the cylinder. The reason is that the light source is no longer in focus for the retina in this (the power) meridian but is in focus for the meridian corresponding to the axis, or no power meridian, of the cylinder. The light which emerges from the cylinder is therefore drawn into a line of light parallel to its axis from which it again spreads out to be ultimately collected into a line, perpendicular to the former line, on the retina. The length of the diffusion line on the retina is exactly equal to the diameter of the diffusion circle created by a spherical lens of the same power.

Whatever form of rod or cylinder is employed, a horizontal streak will be produced when the axis of the rod is vertical and a vertical streak, in turn, when the rod is placed horizontally. In testing latent deviations one eye is left uncovered, except for distance corrections which the practitioner may desire to have worn during these tests, and the rod is inserted before the other eye. The patient is instructed to fix a luminous spot distant some 5 or 6 meters. He should then see the spot and the ribbon of light. If the line appears to pass through the light there is orthophoria: in lateral deviations, if the streak is on the same side of the luminous spot as is the glass rod the diplopia is evidently homonymous, indicating latent convergence, and if on the other side the diplopia is crossed showing exophoria. In the same manner, by making the axis of the rod vertical, a horizontal line of light is produced and latent downward or upward deviations determined.

The question is often asked as to whether the patient fixes the luminous spot (flame) or the streak (line of light). He is free to fix either. In the von Graefe prism test the patient can at will fix either the direct object or the prismatic one, since either eye is able to move so as to receive an image on the fovea of its retina, although such a movement displaces the fixing point of the other eye away from its image. If the alternate fixation makes the line of light shift to considerably different amounts the case is one of anisometropia or paresis. Maddox remarks that alternate fixation can generally be secured by transferring the rods from one eye to the other and "that so delicate a revealer of anisometropia is this procedure sometimes that so small a difference as a quarter of a diopter was once detected (before the

refraction was tried) in a person with one eye emmetropic and the other hyperopic by 0.25 D.''

(c) *Multiple Maddox rods (one before each eye) in tests for cyclophoria.* Imbalances of the oblique muscles, giving rise to cyclophoria, can be detected by the use of a red multiple Maddox rod before one eye and a white Maddox rod before the other, enough prism (base up or down) being inserted before one eye (assume the right) to produce vertical diplopia. (See, however, in this connection the monograph on *The Modern Phorometer* by DeZeng, in which the latest device shows the use of two white multiple rods.) With the axes of the rods vertical two separate and distinct streaks or lines of light will be seen lying in an approximately horizontal plane, the white streak lying below the red one when the white Maddox rod is in front of the right eye. If the streaks appear parallel with each other and horizontal there is no cyclophoria. Should the red streak as seen by the left eye appear horizontal and the white streak seen by the right eye appear at an angle, cyclophoria of the right eye would be shown. Should the white streak tip upwards at the temporal side and approach the red streak the case is one of right plus cyclophoria, whereas right minus cyclophoria would be indicated should the white streak tip temporally downward or away from the upper streak. Such tests may be repeated by placing the prism before the other eye. The degree of either plus or minus cyclophoria may be accurately measured by rotating the respective Maddox rod to such a position as will bring the tilting line into a horizontal plane. The reason for this will be apparent from what follows in the next paragraph.

443. Another most excellent method and used by many practitioners in tests at six meters and one-third of a meter is the double prism with a single horizontal line as a test-object. Before testing the obliques the writer believes that any vertical and horizontal insufficiencies should be corrected. The double prism is then placed, bases horizontal, before one eye. The eye under test is the one before which the double prism is not placed, i. e., the eye seeing the central line. The tests should also be made with and without correcting lenses especially if these contain oblique cylinders. For purposes of emphasizing the physiological and optical principles involved, there are given in Fig. 215 various diagrams to explain the phenomena as subjectively seen by a person having plus cyclophoria of the right eye, i. e., insufficiency of the right superior oblique. Let AB be an arrow used as the object. Under the action of the double prism before the left eye, assuming no cyclophoria of this eye, two horizontal, reversed and inverted images will be received upon the retina as B_1A_1 and B_2A_2 in Fig. 215 (B).

The dotted lines indicate that the horizontal and vertical meridians of this eye are properly held in position. These two images will, therefore, be projected into space and seen as A_4B_4 and A_3B_3 as shown in E. The right eye, under test, having an insufficiency of the superior oblique will, then, under dissociation show an extorsion at the top and an intorsion at the bottom with the result that the vertical and horizontal meridians will be rotated as shown in C. The horizontal arrow will then be imaged upon the retina in C in the position A_5B_5 but will be projected into space as the line A_6B_6 tilting upward at the temporal side as shown in diagram D. Diagram E shows the positions of the three images as viewed by the patient. Other similar analyses can be

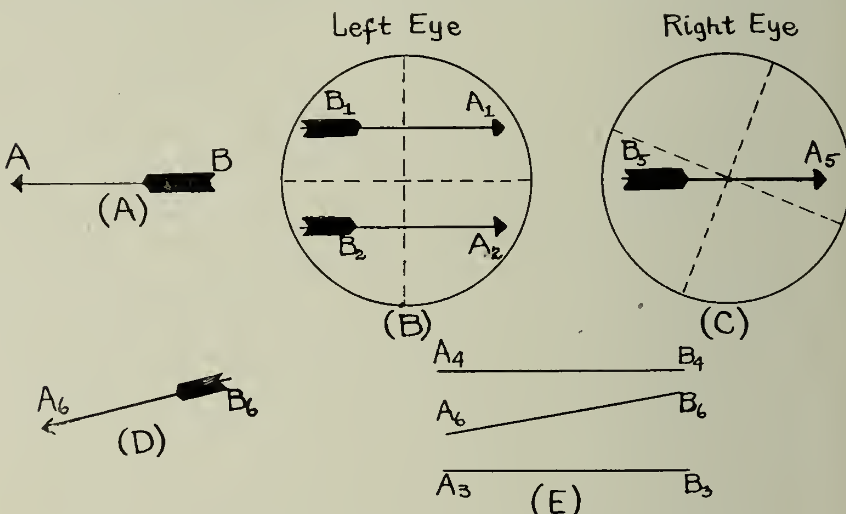


Fig. 215.—Retinal Images and Spatial Projections in Cyclophoria.

made or the indications given by the test memorized as follows: *The central line inclines on the temporal side toward the weaker of the obliques or it points on the nasal side in the direction of the stronger oblique muscle.*

444. In cyclophoria it is difficult to determine whether there is actual insufficiency of the muscles or malposition of the images due to oblique astigmatism when such exists, since it can be demonstrated (*vide* the writings of Savage) that, in astigmatism, there is a displacement of the images of all lines not parallel with the one or the other of the principal meridians and *that these displacements are always toward the meridian of greatest curvature.* False torsion increases with convergence and this may augment or tend to rectify the real torsion caused by deficient oblique muscles. Hence torsion tests made at near points should be

considered in connection with those made at distance. If the torsion is found only at near points (i. e., plus cyclophoria) it may generally be neglected unless the torsion be rather large: in fact the writer believes that, since hyperopia accompanied with esophoria constitutes the major portion of all refractive findings, the slight plus cyclophoria usually found at near points is wholly false as indicative of weaknesses of the obliques. *The condition of ex-cyclophoria in near vision is so common as to deserve being regarded as physiological.* Cyclophoria results chiefly from oblique astigmatism and cannot be measured or corrected with prisms. Steele's rules for the shifting of cylinders for the relief of cyclophoria are given in composite form in Savage's *Ophthalmic Neuro-Myology.*

* * * *

Summary of points relative to the diagnosis and treatment of heterophoria.

445. As a brief summary of some of the important points with reference to the diagnosis and treatment of heterophoria we cite the following:

A. Diagnosis. (1) The measurement of imbalances at six meters by the use of the Maddox rod or double prism and so forth.

(2) Repetition of the measurements with the head placed in different attitudes to make sure, by proving concomitancy, that no paralysis is present.

(3) The amplitude of convergence, or the convergence near point.

(4) The investigations upon the muscular conditions at the reading point: (a) amplitude of accommodation, (b) accommodation and associated accommodative convergence with fusional convergence passive, (c) reserve convergence, (d) conditions of vertical balance and cyclophoria.

(5) Tests upon the breadth of fusion. or prism duction, at six meters; especially the abduction in esophoria and the super- and subduction in hyperphoria to confirm the existence of the heterophoria.

B. Treatment. (1) As a rule prisms are not required and should not be given because heterophoria exists: their necessity must be clearly indicated: their use is often unsatisfactory and harmful.

(2) To determine their necessity, tests must be made with and without corrective lenses in both distant and near vision and on different occasions.

(3) Dependence should be placed largely on tests made with corrective lenses. One is never quite certain, however, as to the true muscular balance until correcting sphericals and cylinders have been worn.

(4) Exophoria and cyclophoria of small amounts in near vision are relatively unimportant, while in distant vision hyperphoria is "at least four times more worthy of notice for each degree than horizontal deviations" (*Maddox*).

(5) If the imbalances cause no symptoms, which is usually the case in low degrees, it is generally better to leave them alone. These indications should, however, aid in the choice of corrective glasses. Hyperopes with esophoria should be fully corrected since the relief of accommodation relaxes the convergence associated with it: hyperopes with exophoria should be undercorrected in many cases (this is the commonly accepted doctrine upon this point but is not satisfactorily substantiated according to the writer's notions upon this subject), and myopes with exophoria should be as fully corrected as seems feasible. Regard must be had in this respect, however, as to whether the correction is for near or distant use since, for example, a myopia with exophoria at distance may exist which exhibits an esophoric condition at near points.

(6) Deviations which demand considerable effort to overcome and where feelings of strain, frontal or occipital headaches and so forth exist, require special attention and investigation. In many cases the writer is confident that the seat of such troubles lies in a weakened fusional convergence, whether this be diverging or converging as the case may be. If these fusion powers (or centers) cannot be further developed by exercise it will often be found advantageous to include small prismatic elements in the corrections prescribed, particularly in those for near work.

(7) In general, as to the amounts of prismatic aid to be given, authorities practically agree upon

(a) Two-thirds of a persistent hyperphoria.

(b) Not over one-half for distance to two-thirds for near in esophoria.

(c) Not over one-third for distance to one-quarter for near in exophoria.

PART SIX

RETINAL AND CHIASMAL IMAGES

XXVII. RETINAL IMAGES

446. *Calculations for sizes of the retinal images in hyperopia and myopia.* This topic has been in part discussed under the caption *Relations between the refractive condition of an eye and its visual acuity* which forms a portion of the discussion on the topic *Form Sense.* We are, however, in the closing section of this treatise desirous of con-

sidering in particular the rôle played by the form and position of the retinal images upon binocular vision.

It has been previously shown that a lens placed in the anterior focal plane of an eye has no effect on the size of the image formed, the latter being merely moved forwards or backwards as the case may be. The image is then the same size as in emmetropia. Hence, in a case of axial anisometropia, if we could place the correcting lens exactly at the anterior focus of each eye, the retinal images would be identical in size. Under these conditions the effect of convex lenses is merely to reduce the divergence of light and that of concave lenses to increase its divergence from each point of the object incident on the optical system of the eye. It is impossible in many cases to make a comparison of the sizes of the images formed because they may not be sharply formed at the retina. In the following statements, therefore, a distinction must be drawn between the image, *I*, actually formed by the dioptric system in the vitreous in front of the retina or that formed back of the retina and the image formed upon the retina in any of these ametropic conditions. For if the retina is not coincident with *I*, the blurred retinal image, owing to the confusion circles, is larger than the ocular image (*I*). As a brief summary we may state that:

(a) In axial hyperopia and axial myopia, the ocular image (*I*) is the same as in emmetropia.

(b) In refractive hyperopia, *I* is larger than in emmetropia.

(c) In refractive myopia, *I* is smaller than in emmetropia.

(d) In refractive hyperopia, *I* is larger than in axial hyperopia when both are accommodated for clear vision.

(e) In refractive myopia, *I* is smaller than in axial myopia when both see clearly the same near object.

(f) In axial hyperopia, with accommodation, *I* is smaller than in emmetropia.

(g) In refractive hyperopia, with accommodation, *I* is nearly the same as in emmetropia.

(h) In axial myopia, the image of a near object seen clearly is larger than in emmetropia.

(i) In refractive myopia, the ocular image of a near object clearly seen is smaller than in emmetropia.

(j) In axial hyperopia and axial myopia corrected by a lens at the anterior focal point, the ocular image is the same as in emmetropia.

(k) In refractive myopia, similarly corrected, *I* is larger than in emmetropia.

(l) In emmetropia, for near vision, *I* is larger with a convex lens than when accommodated.

(m) In hyperopia, I is larger with a convex lens than when accommodated.

(n) In myopia, I is smaller with a concave lens and accommodated than without the lens.

447. *Size of retinal image as affected by position of correcting lens.* Ametropia can, of course, be corrected by a lens which is not coincident with F_A, the anterior focal point of the eye, but, for the same error of refraction, a convex lens must be weaker and a concave lens stronger the farther it is withdrawn. Without entering into the geometrical proof of this and converse theorems, let it suffice for the moment to say that, if the image is formed at the same distance by whatever correcting lens is used and in whatever position it may be placed, we know that

(a) A convex lens placed in front of the anterior focal point, F_A, the image is larger.

(b) A convex lens placed behind F_A, the image is smaller.

(c) A concave lens placed in front of F_A, the image is smaller.

(d) A concave lens placed behind F_A, the image is larger.

The size of the image after refraction through any optical system is obtained from the equation

$$\frac{I}{O} = \frac{F_A}{a} \quad \dots\dots (1)$$

where I is the size of the image, O the size of the object, F_A is the anterior focal length and a is the distance of the object from the anterior focus of the system.

If a lens be introduced before the eye we have a new optical system and as before, the size of the image formed by this new system will be found from the equation

$$\frac{I_1}{O} = \frac{F}{a_1} \quad \dots\dots (2)$$

in which a_1 represents the distance of the object from the new anterior focus and F represents the new focal distance. Hence the relation of the size of the image with the lens to that without the lens is expressed by the equation

$$\frac{I_1}{I} = \frac{a \times F}{a_1 \times F_A} \quad \dots\dots (3)$$

When the distance of the object is great in comparison with the change in position of the anterior focus caused by adding the new lens, then a and a_1 may be considered identical and hence

$$\frac{I_1}{I} = \frac{F}{F_A} \qquad \text{.......... (4)}$$

But F, the focal length of the new or combined system of eye and lens, is derived from the general equation

$$F = \frac{F_1 F_A}{F_1 + F_A - e} \qquad \text{.......... (5)}$$

and making this substitution, we have

$$\frac{I_1}{I} = \frac{F_1}{F_1 + F_A - e} \qquad \text{.......... (6)}$$

In this equation F_1 is the focal length of the lens, F_A is the anterior focal length of the eye and e is the distance between the eye and the lens. This formula is sufficiently accurate to determine the effect of correcting lenses upon retinal images except in the case that the object is near the eye. We shall now examine briefly the condition when a and a_1 cannot be considered identical. By a somewhat detailed but not difficult process of analytical reasoning it can be shown that

$$\frac{I_1}{I} = \frac{F_1}{F_1 + (F_A - e) + \left(\frac{F_A - e}{a}\right)^2} \qquad \text{.......... (7)}$$

This is the general expression for the magnifying power of any lens in combination with the eye or with any other optical system. If we examine this expression we see that if $F_A = e$, i. e., if the lens be placed at the anterior focus of the eye, then $\frac{I_1}{I} = 1$. If, again, the the lens be convex and F_A be less than e, that is, if the lens be without the anterior focus of the eye, then $F_A - e$ will be negative, but $(F_A - e)^2$ will be positive. Varying values of these two quantities and of the value of a give rise to the conclusions in the form of the four statements which we have made in the preceding paragraph. For example, we observe from a study of equation (7) that as e, the distance between the lens and the eye, varies, the magnifying power varies: when this distance becomes such that $e - F_A = F_1 + \frac{(F_A - e)^2}{a}$,

the denominator of the expression for the magnifying power becomes zero and $\frac{I_1}{I}$ equals infinity. If we solve the equation

$$e - F_A = F_1 + \frac{(F_A - e)^2}{a} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

we obtain the relation between $e - F_A$ and a, which exists when I_1/I is infinity. This relation becomes, by the solution of equation (8),

$$e - F_A = \frac{a}{2}\left(1 \pm \sqrt{1 - \frac{4F_1}{a}}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Since the square root of a negative quantity cannot be actually extracted, the function $\frac{4F_1}{a}$ must be less than unity or equal to it. Hence the least value which a can have and satisfy the condition that $\frac{I_1}{I}$ = infinity is that $a = 4F_1$. When $a = 4F_1$, we find the corresponding value of $e - F_A$ to be $\frac{a}{2}$. We thus obtain a basis for the following rule relative to the effect of changing the position of the lens, to wit:— As a convex lens is removed from the eye, the magnifying power increases so long as the distance of the object from the lens is more than twice the focal length of the lens and when the distance between object and lens is less than twice the focal length of the lens the magnifying power is diminished by further removal of the lens from the eye. If, with a convex lens, $F_A - e$ is positive, which means that the lens is placed within the anterior focus of the eye, then I_1 will be less than I. If this lens is concave, i. e., F_1 is negative, our equation shows that when F_A is less than e, or when the lens is without the anterior focus of the eye, I_1 is less than I except when $a = e - F_A$; in this case, as with convex lenses, I_1 and I are equal.

448. *Some simple conclusions as to retinal images in ametropia.* The object and its image subtend equal angles at the nodal point, so that the image of an object which subtends a given angle at the nodal point depends on the distance the axial rays travel before the image is formed. If the latter is at the retina the size of the retinal image is to the size of the object as the distance between the nodal point and the retina is to the distance between the nodal point and the object.

Taking the nodal point of the reduced eye as 15 mms. from the retina and letting I represent the size of the image, O the size of the object and f_1 the distance of the object from the nodal point we have,

$$I = 15 \frac{O}{f_1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

This formula gives us a simple means of calculating the approximate sizes of the retinal images in ametropia, always assumed to be axial however. For the number 15 mms. in equation (10) is assumed to be the distance from the nodal point to the retina in emmetropia and in ametropia it is known that 3 D. of axial error are equivalent to an increase of 1 mm. depth of the eye dependent upon whether it is myopia or hyperopia under consideration. In a hyperopic (axial) condition of 6 D. the constant would be 13 mms. and in myopia (axial) the constant would be 17 mms. and the ratio of the retinal images I_1 and I_2 would be expressed as

$$\frac{I_1}{I_2} = \frac{13 \dfrac{O}{f_1}}{17 \dfrac{O}{f_1}} = \frac{13}{17}.$$

Such calculations, as far as exactness is concerned, are of little utility, however. For in myopia, the image would be extremely blurred unless the object were at the punctum remotum and in hyperopia with accommodation relaxed it would be similarly blurred and if accommodation is in vogue the optical system is considerably changed; this is true also for a myopic eye accommodating within its far point.

Equation (4) may be written as

$$\frac{I_1}{I_2} = \frac{F_{A1}}{F_{A2}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

in which the subscripts indicate the sizes of images or the anterior focal lengths in two conditions of the ocular system fixing the same point presumably at a large distance from the eye. We can, therefore, find the approximate values of F_{A1} and F_{A2}, the anterior focal lengths in two ametropic conditions, and hence find the relative sizes approximately of the retinal images. Taking the equations of the reduced eye we find that the relation between posterior focal length, F_B, anterior

focal length, F_A, and indices of the media, $n_1 = 1$ and n_4 (assumed water) $= 1.33$, is given as

$$\frac{F_A}{F_B} = \frac{n_1}{n_4} = \frac{3}{4} \qquad \text{(12)}$$

A double use of equation (12) will give the relation that

$$\frac{F_{B1}}{F_{B2}} = \frac{F_{A1}}{F_{A2}} \qquad \text{(13)}$$

This equation, taken in conjunction with equation (11), gives the solution that

$$\frac{I_1}{I_2} = \frac{F_{A1}}{F_{A2}} = \frac{F_{B1}}{F_{B2}} \qquad \text{(14)}$$

This is in accord with the statement given in conjunction with equation (10). If, for example, the posterior focal lengths in two cases

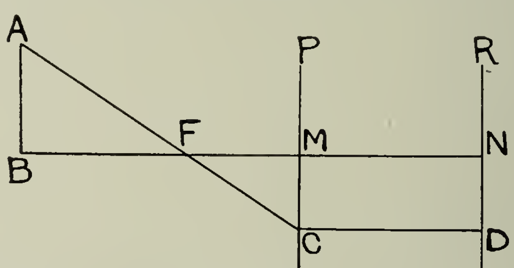


Fig. 216.—Illustrating the Method of Determining the Size of the Retinal Image.

are 18 mms. (6 D. of hyperopia) and 22 mms. (6 D. myopia), assuming 20 mms. as normal, we find that the ratio of the sizes of the retinal images according to equation (14) is 18/22.

449. The foregoing calculations are not, of course, strictly accurate. The formula for calculating the size of the retinal image deduced from the relation existing between the distance of the object to the nodal point and the nodal point to the retina is only true providing the object is at such a distance that no accommodation is exerted and the length from the cornea to the nodal point is so small as to be negligible in comparison with the object distance. When the object is brought sufficiently close these assumptions no longer hold, since either the image is no longer sharply formed at the retina or the image is formed sharply at the retina by means of accommodation. The focal lengths of the system in the latter case are shortened, the

nodal point is advanced and the distance of the image from the cornea is now a posterior conjugate focal distance and not a principal focal distance. The following demonstration includes the necessary corrective factors so that the final result, based upon the influence of the anterior focal length upon the size of the retinal image, is of general application. Let *BMN* be the principal axis of a reduced eye, in Fig. 216, of which *P* is the cornea or refracting plane and *R* the retina. Let *AB* be the object at a comparatively short distance such that accommodation is necessary in order to retain the image on the retina. A ray, *AC*, passing through the anterior focus, *F*, of the accommodated eye will proceed after refraction parallel to the principal axis and determine the size of the retinal image *ND*. Let the *distance of the object from the cornea* be f_1 and let f_2 be the posterior conjugate focus, *MN*, which is a fixed value in any particular case, since the image is to be formed at the retina. In order that *MN* may remain upon the retina, the value of *F*, the anterior focal length, can be found from the equation

$$\frac{1}{f_1} + \frac{\mu}{f_2} = \frac{1}{F} \quad \dots\dots\dots\dots (15)$$

$$\text{or} \quad F = \frac{f_1 f_2}{\mu f_1 + f_2}$$

When $= 4/3$ and $f_2 = 20$ mms., we find that

$$F = \frac{20f_1}{4f_1/3 + 20} = \frac{15f_1}{15 + f_1}$$

$$\text{But} \quad \frac{MC}{AB} = \frac{FM}{BF} = \frac{F}{f_1 - F} \quad \dots\dots\dots\dots (16)$$

and by substitution of the value of *F* in this last equation we have

$$ND = \text{retinal image size} = \frac{15 \times \text{size of object}}{f_1}.$$

This is strictly accurate for all values of f_1 *measured from the cornea.*

450. The equation (15), $\frac{1}{f_1} + \frac{\mu}{f_2} = \frac{1}{F}$, is of service in enabling us to calculate and compare the sizes of the retinal images when a near object is seen by an emmetropic, hyperopic or myopic eye: in each

instance the object viewed is to be taken close enough to the eye so that accommodation is involved and the assumption made that the image is in each case formed upon the retina. As an ilustration, let it be required to find the relative sizes of the retinal images when an object at 30 cms. is viewed by (a) an emmetropic eye, (b) an eye myopic 3 D. and (c) an eye hyperopic 3 D. Again assuming the emmetropic eye to have a posterior focal length, f_2, equal to 20 mms. and that 3 D. of refractive error are to be considered as indicating an axial change of one diopter, the equations are:—

(a) Emmetropia $\frac{1}{30} + \frac{4/3}{2} = \frac{1}{F}$ or $F_E = 1.43$ cm.

(b) Myopia $\frac{1}{30} + \frac{4}{6.3} = \frac{1}{F}$ or $F_M = 1.49$ cm.

(c) Hyperopia $\frac{1}{30} + \frac{4}{5.7} = \frac{1}{F}$ or $F_H = 1.36$ cm.

Referring to Fig. 216 and employing equation (16) we find that the retinal images, in order of their sizes, are:—myopia, $\frac{1.5}{28.5} \cdot O$, emmetropia $\frac{1.43}{28.57} \cdot O$ and hyperopia $\frac{1.36}{28.64} \cdot O$, in which O represents the size of the object. We thus see that if an eye which is myopic 3 D. and an emmetropic eye which is accommodated 3 D. observe an object at 33 cms. the retinal image is larger in the former condition. We likewise see the basis for the following statements: (a) in emmetropia, for near vision the image is larger with a convex lens than when accommodated; (b) in hyperopia, the image is larger with a convex lens than when accommodated and (c) in myopia, the image is smaller with a concave lens and accommodated than without the lens.

451. *Retinal images and binocular vision in anisometropia.* In this connection we shall discuss the accomplishment of vision in anisometropia when this inequality in refractive condition is myopic or hyperopic and shall reserve for subsequent consideration the rôle played by astigmatism in altering the forms of retinal images and the effects thereby produced in monocular and binocular vision. The ideal condition of a pair of eyes which are not refractively normal is known as isometropia: there is in a goodly proportion of persons,

however, an appreciable difference of refraction in the two eyes or what is specified as *anisometropia*. But anisometropia is to be considered a defect only when it is sufficient to cause some disturbance either visual or nervous. The least refractive difference which may be regarded as an anomaly varies with the degree of refractive error in the eyes. For example, if one eye is emmetropic while the other has 2 D. of myopia, there would be no hesitancy in classing this inequality as a defect capable of giving rise to very great disturbance, especially in binocular vision: but if one eye has 8 D. and the other 10 D. of myopia the same anisometropia (2 D.) is a subordinate factor. The chief reason why such an anisometropia can cause disturbance in the one case and not in the other should be apparent to the reader from the discussion which has preceded and dealt with the relative sizes of retinal images in various ametropic conditions, both at distant and near points, when accommodation may or may not be demanded. Certainly the sizes of the retinal images in the case of one eye emmetropic and its mate fairly myopic or hyperopic will be proportionately much more different and have much greater differences in sharpness of outline than in the case of two eyes, both highly myopic or hyperopic, and yet differing by one or two diopters, in which the sizes of the retinal images and their distinctness will not be appreciably varied the one from the other.

Vision in anisometropia may be accomplished in one of three ways. (1) There may be binocular vision: (2) vision may be monocular, either eye being used alternately, and (3) vision may be monocular to the exclusion of the other eye.

452. When it has been ascertained by means of the stereoscope or other test that an anisometrope possesses binocular vision, the question arises as to how such vision is accomplished in these cases. There are two possibilities: either by the exercise of a greater amount of accommodation in one eye than in the other or by the mental fusion of the clear image as formed in the adapted eye with the blurred image present in the other. The majority of practitioners and ocular experimentalists consider the premise that ocular adjustment in both eyes for an object lying within the range of accommodation of each eye may be attained by accommodating unequally for each eye as impossible. This theory of unequal accommodation has, however, received support from Fick, who cites a number of cases in evidence of his opinion that the refraction is equalized by unequal action of the ciliary muscles. He, in turn, has been refuted by Hess, who, from a number of experiments, concludes that there is no evidence in support of unequal accommodation. Fick, in his *Diseases of the Eye and Oph-*

thalmoscopy, cites the following case in support of his contention:—"The shadow-test disclosed (in a certain case) compound hyperopic astigmatism: the test letters showed this condition only in the left eye, while the right eye accepted a cylindrical but no spherical lens. I concluded that in the right and more acute eye there was latent hyperopia but in the left eye manifest hyperopia as well. Two doses of homatropin proved that my assumption was correct, for not only the left but the right eye also accepted a spherical lens—on the right a lens of + 3 D. If this clearly indicated unequal accommodation, it became a certainty when I had occasion eight days later to test the glasses prescribed by me. I examined the patient again with the following result: while the right eye, with a simple cylindrical lens, was fixing letters (D = 4) at 4 meters, the refractive condition of the left eye was determined by skiascopy; then the test letters were removed, and as the right eye was gazing into space, the left eye was again tested by skiascopy; in both cases the refractive condition of the left eye remained the same, that is, unchanged, while the refractive condition of the right eye had varied to the extent of 3 D." This problem seems to be similar to that of dynamic compensatory astigmatism. We do not have, however, good reasons for believing that the ciliary muscle of one eye can be innervated alone, or that when both muscles are innervated one can receive a greater impulse volitionally than the other. It is possible that Fick's results may be interpreted otherwise than as supporting a view of unequal accommodation; for a stimulation of the accommodation-center may give rise to greater actual contraction of the muscle in one eye than in the other. It is likewise possible that because of unequal sclerosis the same impulse may produce a greater change in the curvature of the lens in one eye than in the other. The writer believes that these two explanations are wholly adequate to explain these unequal accommodations.

453. Alternate vision in anisometropia generally occurs when one eye is emmetropic—or practically so—the other eye having a diopter or two of myopia (or hyperopia) and possessed of good visual acuity. Such an anisometrope enjoys a certain advantage in that his distant seeing is done with the emmetropic (or hyperopic) eye and his near work by the myopic eye.

In the majority of cases demanding the services of a refractionist the ametropia of one eye will differ slightly from that of its fellow. Appropriate corrections are ordered in such cases. It is equally logical to attempt to restore normal relationships when the dissimilarity is more marked. Such corrections cannot be tolerated by many persons; if, however, the patient is young and unhindered by latent

squint the anisometropia should in general be totally neutralized for the patient will grow accustomed to the glasses after a short period of discomfort. The explanation of this intolerance and discomfort is found, in part, in the nerve disturbance occasioned when an eye which has previously acted solely in a subordinate capacity in vision is suddenly put in condition to co-operate with its mate and again, in part, in the secondary effects of lenses. For, if a correcting lens is worn in the anterior focal plane of the axially ametropic eye there will be formed an image equal in size to that obtained in emmetropia. If both eyes are properly corrected their retinal images should be of equal size. The disturbance cannot, therefore, be attributed in this case to unequal retinal images but rather to a change in ocular habits of seeing to which the person has become accustomed.

454. Convex lenses lead an observer to suppose that the object is

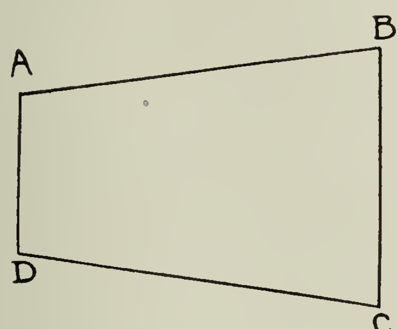


Fig. 217.—Apparent Alteration in the Size of an Object Produced by Anisometropia.

more remote than it is by reason of the diminution of accommodation required to see an object distinctly and consequently they make the object appear larger than it is as seen with the naked eye. This apparent alteration in the size of an object produces in anisometropia a one-sided disturbance. If a rectangular diagram is placed in front of, and equidistant from, the two eyes (assumed equal or, for example, emmetropic) and viewed binocularly with a convex lens before the right eye the rectangular shape of the object will be destroyed, for the right side will appear broader than the left as illustrated in Fig. 217. If a concave lens is used before the right eye, the right side of the diagram will appear smaller than the left. This disparity arises because of the fact that the right eye is chiefly concerned in looking at the right side of the object. The apparent alteration is due to a disturbance of accommodation; for the effort of accommodation demanded of the left eye in adjusting itself for the left side of the

figure is greater than is demanded of, or is more than sufficient for, the right eye wearing a convex lens, consequently the impression arises that the right side is farther away and larger than the left side.

455. *Effects of cylindrical lenses upon the sizes of retinal images.* The formulæ which have been deduced for spherical lenses are also applicable to cylindrical corrections. The action of this latter class of lenses is confined to the meridian at right angles to the axis of the lens; hence the remarks made as to the effects of spherical lenses upon the size of retinal images apply also to cylinders with the restriction that the effect is confined to the refracting meridian since no effect is produced by a cylindrical lens in the meridian of its axis. Astigmatism in general is a curvature defect while hyperopia and myopia are largely axial defects. The effect of astigmatism upon retinal images

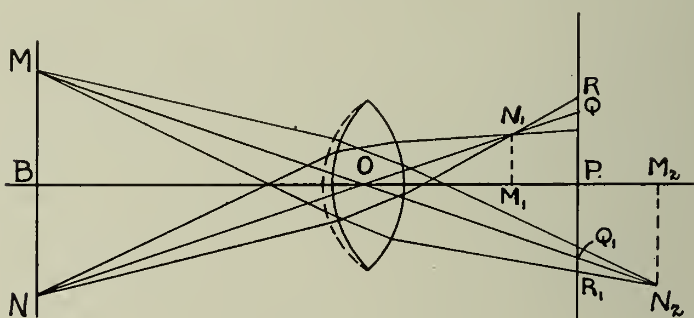


Fig. 218.—Effects of Astigmatic Errors Upon the Size and Position of the Retinal Images.

will, therefore, not be analogous to that of axial ametropia. For if an eye is hyperopic in one meridian and emmetropic in the meridian at right angles thereto, the defect in curvature in the hyperopic meridian is the same as though a concave cylinder were placed in contact with a normal cornea. Such a lens would be within the anterior focus of the eye and its effect would be an enlargement of images in the refracting meridian of the lens. Since the curvature of the eye is less in the hyperopic than in the emmetropic meridian, the anterior focal length is greater in the abnormal than in the normal meridian. Consequently the image of an object will be too large in the former meridian, for the size of the image is proportional to the anterior focal distance. In this same way we find that, in myopic astigmatism, the image is too small in the myopic meridian. Fig. 218 shows the effect of the faulty position of the retina, for it must be remembered that the retina is not in the proper position to receive an

accurately focused image in the faulty meridian. Let B and P be conjugate points and hence the image of BN be at PQ. If now the retina remain at P while the lens is changed in curvature, and therefor power, so that M_1 and B are conjugates, then the true ocular image M_1N_1 will be smaller than PQ, but the indistinct image as received upon the retina will be larger as represented by PR. In a similar manner, if B and M_2 are conjugates, it is apparent that both the focussed and blurred images will be larger than normal but the blurred image will be less enlarged than the other.

456. We can now understand the influence of cylindrical lenses used for spectacle purposes upon retinal images. A properly selected convex cylindrical lens brings the image of an object to an accurate focus on the retina but this image is enlarged in the meridian of maximum power of the cylinder or in the meridian at right angles to the axis of the cylinder. For if the lens is placed at the anterior focus of the eye, the new image will be of the same size as M_2N_2 (Fig. 218) since the effect of the lens is to bring the image forward without changing its size. If the correcting lens is worn without the anterior focal point of the eye the new image will be larger than M_2N_2. In either of the specified lens positions, therefore, the retinal image will be larger than the blurred image PR_1 which is received upon the retina when no correcting lens is worn and larger than $PQ_1 = PQ$, the normal image. A properly selected concave cylinder, in turn, throws the image back upon the retina and causes a decrease in the size of the image in the refracting meridian of the lens. If the correcting concave cylinder is worn at the anterior focal point of the eye, M_1N_1 (Fig. 218) will represent the size of the new image. Under any conditions, practically, of lens position the retinal image will be smaller than the blurred image PR_1 which the eye receives without lenses and smaller than PQ, the normal image. We come, therefore, to the general conclusion that cylindrical lenses, worn as spectacles, do not under any circumstances produce normal retinal images, for all objects are magnified in the refracting meridian of a convex lens and minified in this meridian by a concave cylindrical glass. If the correcting cylinder could be worn in contact with the cornea, the seat as a general rule of defective curvature, normal images would result.

In Fig. 219, let A represent a rectangular object. Then if it be viewed through a spherical lens held *beyond its focal length* from the eye, B will represent the appearance of the object. If a cylindrical lens is used with axis vertical, C will represent the object as it will appear to the observer; the cylindrical lens has the same effect as the spherical one in deviating the rays in the meridian at right angles to

the axis of the lens, i. e., rays from the right of the object are made to cross over and intersect on the left and vice versa. The object is therefore reversed in this direction but is not so affected in the meridian parallel to the axis of the lens for in this meridian the rays are not deviated by the lens. In a like manner *D* represents the object

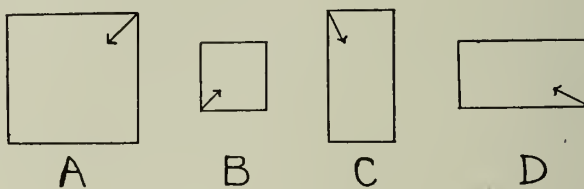


Fig. 219.—Rectangular Object.

A, As seen normally; B, as seen through a spherical lens held beyond its focal length; C, as seen through a cylindrical lens similarly placed with axis vertical and D, as viewed through a cylindrical lens with axis horizontal and similarly placed.

as it would appear when viewed through a cylindrical lens with axis horizontal.

457. *The twisting properties of cylindrical lenses and ocular astigmia.* In view of the preceding considerations as to the effects of cylindrical lenses upon retinal images it follows that if a person holds

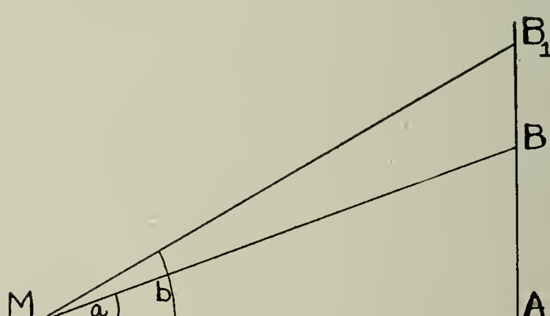


Fig. 220.—Illustrative of the Twisting Properties of a Cylinder.

such a lens in front of the eye and views a distant rectangular object—such as a window-frame or picture—through it there will be formed a distortion of the object which will change with every variation of the position of the lens. If the axis of the cylinder is parallel to one of the sides of the object the rectangular form of the object will remain but the ratio of the sides will be altered (see Fig. 219). If the lens is rotated in its own plane, the distortion will not now be confined simply to the apparent size of the object but will also affect the

direction of the lines forming the sides so that the rectangular object will assume the form of an oblique parallelogram.

Let MA, Fig. 220, be a line parallel to the axis of a cylindrical lens and let AB be perpendicular to its axis. The retinal image of the line MA will be the same with or without the cylinder. If one looks at the line AB and if the lens is convex, then AB will be magnified and will appear, for example, as AB_1. If, therefore, any oblique line, MB, is looked at, its direction will be changed and it will assume the position MB_1. Hence, any line not parallel or perpendicular to the axis of a cylindrical lens undergoes an angular deviation when viewed through such a lens. If a is the angle which the line makes with the axis and b is the angle which the line apparently makes with the axis, we may write

$$\frac{\tan b}{\tan a} = \frac{AB_1}{AB} = m,$$

in which m represents the magnifying power of the lens. When the lens is a concave cylinder, m is less than unity and the line MB_1 appears to be in the position MB.

458. We have seen that retinal images in astigmatic eyes are not normal in their proportions; we have seen also that the effect of astigmatism upon retinal images is analogous to that of cylindrical lenses placed in contact with a normal cornea. A cylindrical lens thus placed would have a magnifying or minimizing action on images in the direction of the refracting meridian of the cylinder; it is upon this property that the apparent deviation of lines depends. It is, therefore, clear that in astigmatic eyes all lines not parallel or perpendicular to the axis of the astigmatism are twisted out of their proper relations. A rectangle whose sides do not correspond in direction with the meridians of greatest and least refraction appears as an oblique parallelogram. Since the dioptric power of the eye is relatively great in comparison with the amount of astigmatism, however, the distortion is small. The defect is not appreciable to a person whose eyes are astigmatic, even in astigmia of high degree; when, however, the astigmatism is corrected by a suitable lens complaint is frequently made of annoying distortion of lines (metamorphopsia). In general this disturbance is transient: since a cylindrical lens as worn before the eyes cannot reduce the retinal image to its proper proportions it is evident that it cannot correct the distortion of lines and it is easy to see why annoyance should arise when glasses are first worn. (See article by J. A. Lippincott on "Binocular Meta-

morphopsia Produced by Optical Means," *Archives of Ophthalmology,* 1917.)

459. G. C. Savage, in his books on *Ophthalmic Myology* and *Ophthalmic Neuro-Myology* as well as in his essay on **Oblique astigmatism** in this *Encyclopedia,* Volume XI, has dealt with the subject of retinal images produced under various conditions of astigmia and has shown their influence upon fusion and binocular vision in a most delightfully analytical and scientific manner. We shall quote, in the succeeding paragraphs, quite freely from his writings: at least many of the essential ideas herein involved are taken from this writer.

460. In emmetropia, hyperopia and myopia there is no displacement of the images and, therefore, the law of corresponding retinal points is satisfied when the oblique muscles obey the subordinate law governing them, i. e., when they parallel the vertical axes with the median plane of the head. In vertical and horizontal astigmatism there is no displacement of images of vertical and horizontal lines but images of oblique lines are displaced: this displacement is in the same direction and to the same extent in the two eyes, hence the law of corresponding retinal points can be satisfied only when the law governing the obliques is satisfied and obeyed. In oblique astigmatism, however, in which the meridians of greatest curvature either diverge or converge above, the images of vertical and horizontal lines are displaced so that they no longer bear a proper relationship to the lines themselves; hence the images must fall on non-corresponding retinal points or, more properly, non-corresponding lines. As a result, in such eyes no line in space can have both images properly related to it, for a line that would be parallel with the meridian of greatest curvature of one eye would not be parallel with the meridian of greatest curvature of the other. Hence, the two images of any line cannot fall on corresponding retinal parts when in oblique astigmatism the meridians of greatest curvature are not parallel. In order, therefore, to harmonize these images and to satisfy as perfectly as possible the law of corresponding retinal points, "the individual law governing the obliques must be suspended and the vertical axes of the eyes must be made either to converge or diverge above,—the former if the meridians of greatest curvature diverge above, the latter if these meridians converge above. The same is true when the principal meridians of one eye are vertical and horizontal, while those of the other are oblique."

In astigmatism there is displacement of the images of all lines not parallel with the one or the other of the two principal meridians. The obliquity of retinal images was first demonstrated in 1890 by Savage

and his collaborator Lowry by the production of artificial oblique astigmatism and at that time the following important law was formulated: *"The retinal image is displaced toward the meridian of greatest curvature."* "This being true—and there is no exception to the rule—the image of a vertical or horizontal line is displaced toward the meridian of best curvature in oblique hyperopic astigmatism, from the best meridian in oblique myopic astigmatism and toward the myopic meridian in oblique mixed astigmatism."

461. Fig. 221 shows a square as seen by a non-astigmatic eye, as seen by an eye astigmatic according to the rule and as seen by the latter after the astigmatism has been corrected by a plus cylinder.

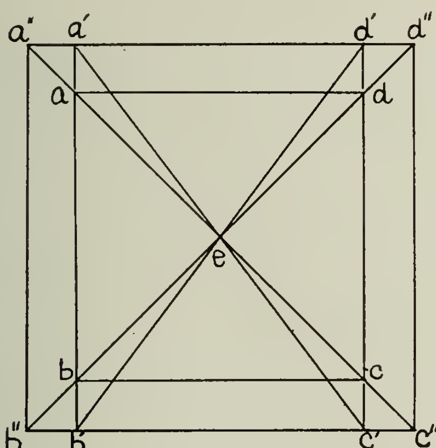


Fig. 221.—Representing a Square as Seen by (a) Non-Astigmatic Eye; (b) an Eye Astigmatic According to the Rule, and (c) as Seen by the Latter After Correction by a Plus Cylinder. (After Savage.)

The rectangle *abcd* is the square seen by a non-astigmatic eye and *ac* and *db* represent the diagonals. The rectangle *a′b′c′d′* is the square as seen by the astigmatic eye with the meridian of greatest curvature vertical. The refraction of the axial rays from *a* and *b* by the astigmatic cornea is such as to make them cross each other on the way back to the retina sooner than they would have in the absence of astigmia: hence their points of impingement on the retina are more widely separated and the line itself is proportionately increased. Therefore the line *ab* must become the line *a′b′* and the line *dc* the line *d′c′* and, since *ad* and *bc* are not affected in size, the original square becomes a rectangular parallelogram *a′b′c′d′*. The diagonal *ac* has been rotated toward the vertical and become *a′c′*, while the diagonal *db* has been

rotated in the opposite direction, but also toward the vertical, and becomes $d'b'$. *They have both been rotated by the refraction of the astigmatic cornea toward the meridian of greatest curvature.* The image changes, therefore, effected by the astigmatic cornea are: (a) an increase in the length of the lines parallel with the meridian of greatest curvature, (b) an increase in the distance between the lines parallel with the meridian of least curvature and (c) a corresponding rotation of the diagonal toward the meridian of greatest curvature. The giving of the proper lens, i. e., plus cylinder, to this eye affords such aid as to make its refractive power in the least curved meridian equal to the unaided refractive power of the meridian of greatest

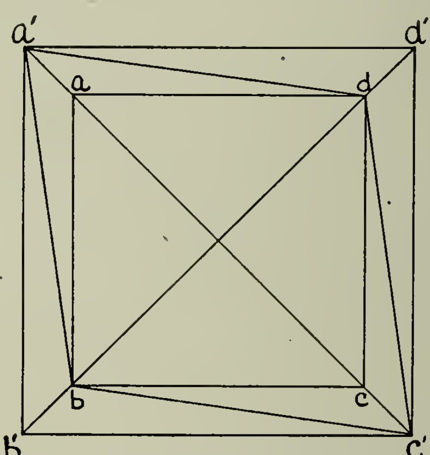


Fig. 222.—Representing the Image Changes when the Astigmatism is Oblique, the Meridian of Greatest Curvature Being at 135 Degrees. (After Savage.)

curvature. The result will be a lengthening of the horizontal lines $a'd'$ and $b'c'$ into the lines $a''d''$ and $b''c''$ and a displacement of the lines $a'b'$ and $d'c'$ until they become $a''b''$ and $d''c''$. The final figure $a''b''c''d''$ as seen by the corrected astigmatic eye is a square. The cylinders, by changing the rectangular parallelogram $a'b'c'd'$ to the square $a''b''c''d''$, has also rotated the diagonals $a'c'$ and $d'b'$ back to their original positions.

462. Fig. 222 shows the image changes when the astigmatism is oblique, the meridian of greatest curvature being at 135°. That portion of the diagram lettered *abcd* shows an original square for a non-astigmatic eye. In an obliquely astigmatic eye the diagonal *ac*, being at an angle of 135°, is in the plane with the meridian of greatest curvature, while the diagonal *db* is in the plane with the meridian of

least curvature. The diagonal *ac* is increased in length by the astigmatism into *a′c′* for reasons already given, while the diagonal *db* is neither altered in size nor direction. The sides of the square, not being parallel with the principal meridians, must be rotated toward the meridian of greatest curvature, *ab* becoming *a′b, ad* becoming *a′d, bc* becoming *bc′* and *dc* becoming *dc′*. The figure *a′b′c′d* is a non-rectangular parallelogram which leans down and to the right. A plus cylinder correcting the astigmatism will increase the length of the diagonal *db* into *d′b′* to the exact length of the diagonal *a′c′* and at the same time will so rotate the sides *a′b, a′d* and so forth as to convert the non-rectangular parallelogram *a′bc′d* into the magnified square *a′b′c′d′*.

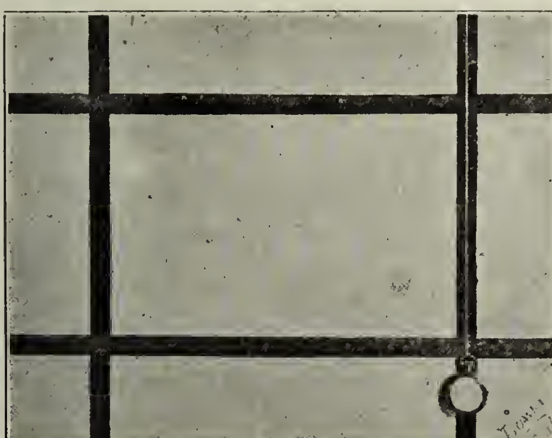


Fig. 223.—Photograph of Rectangular Frame through High Grade Camera Lens. (After Savage and Lowry.)

463. It is evident that, if the astigmatism is equal and of the same kind in the two eyes, the meridians of greatest curvature being parallel, though oblique, the two images of a square held vertically will be distorted alike and hence can be fused readily and completely. If the meridian of greatest curvature in the right eye is at 135° and in the left eye at 45°, the image in each eye will be a parallelogram leaning in the opposite direction from the image in the other eye. The two cannot be perfectly fused though an attempt at fusion will be made in an effort on the part of the eyes to obey the law of corresponding retinal points which is the supreme law of binocular single vision. The fusion of two images in astigmia at axes 135° and 45° respectively, would give an objective square the appearance of a

trapezoid with the longer base uppermost. The fusion would be effected by the superior obliques converging the vertical axes of the eyes.

464. The obliquity of retinal images can be demonstrated by the results obtained with a camera. If the camera is properly focussed we have a representative emmetropic eye. By placing a concave cylinder in apposition to the camera lens an artificial hyperopic astigmatism is created and the effects upon the images can be investigated when the astigmatism is "with" or "against" the rule or oblique. Lowry carried out such a series of investigations and they are reproduced in Savage's writings. Fig. 223 shows that there is

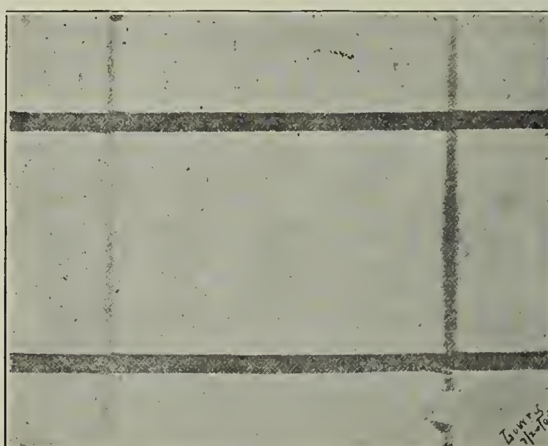


Fig. 224.—Photograph of Rectangular Frame Through Camera Lens Carrying in Front of Itself a Cylinder Producing Simple Vertical Hyperopic Astigmatism. (After Savage and Lowry.)

obtained a perfect rectangle, sharp and distinct, such as would be seen by an emmetropic eye, when the focus is accurately adjusted.

465. In Fig. 224 the axis of a minus 3 D. cylinder was placed at 90° in apposition to the camera lens, hence producing simple vertical hypermetropic astigmatism. The meridian of greatest curvature is at 90° and of least curvature is at 180°. The reproduced photograph shows a perfect rectangle with its horizontal line sharply defined and the vertical very indistinct.

466. If, however, there is placed before the camera a cylinder of about 3 D. power with its axis at 135° and in addition a + 1.50 D. sphere—in order to give the middle of the focal interval without changing the focus of the camera—a non-rectangular parallelogram is formed as shown in Fig. 225. Every point is equally indistinct and

nowhere are the lines at right angles as in the original. The vertical lines deviate to the right at the top and to the left at the bottom, while

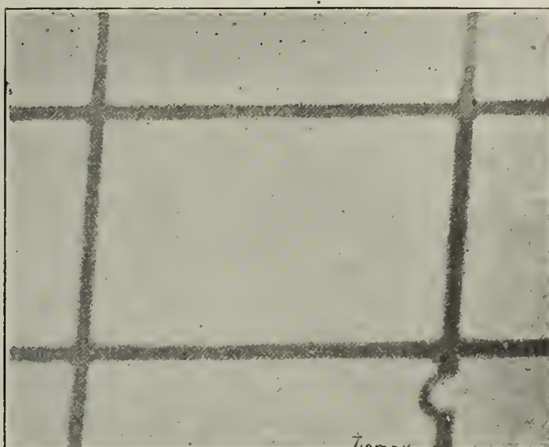


Fig. 225.—Photograph of Rectangular Frame Through a Camera Lens Carrying in Front of Itself a Cylinder at Axis 135 Degrees. (After Savage and Lowry.)

the horizontal lines are elevated at the right and depressed at the left. (Note:—These points are all the reverse of the images, therefore the reverse of the object as it would be seen.)

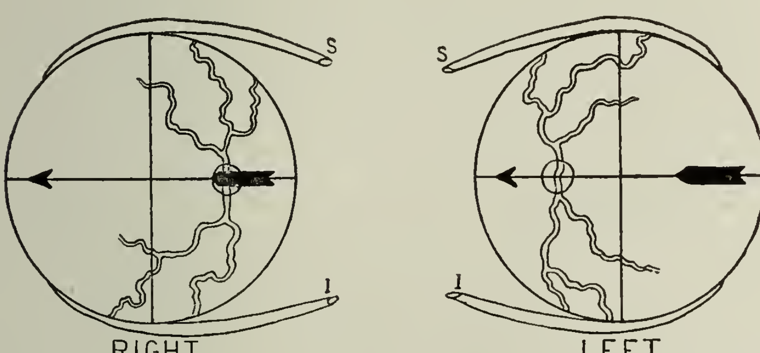


Fig. 226.—Representative of a Pair of Eyes in which the Two Principal Meridians are Vertical and Horizontal. (After Savage.)

Any reader may at his pleasure test out these monocular effects as well as those to be briefly considered from the binocular single vision viewpoint by making himself astigmatic by the addition of a 4 or 5 diopter cylinder (either plus or minus) and viewing a rectangular card through the cylinder placed at various angles.

467. The degree of the displacement or distortion (*Fr.* dénivellation) is proportional to the degree of astigmatism and to the inclination of the principal meridians with respect to the object fixed. Fig. 226 represents the retinal image of a horizontal arrow formed by a pair of non-astigmatic eyes or by eyes having astigmatism in vertical—horizontal meridians. In either case there will be no displacement of

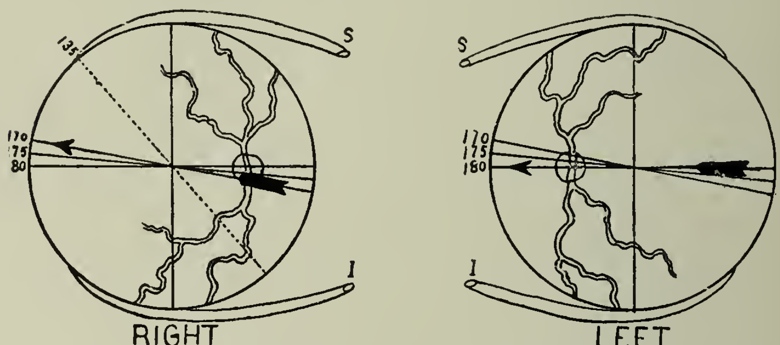


Fig. 227.—Representative of a Pair of Eyes.

Left eye has its best meridian at 90° while the right eye has its best meridian at 135° as shown by the dotted line. (After Savage.)

vertical or horizontal objects. For in either anastigmatic eyes or those having their principal meridians vertical and horizontal all points of an object situated in the plane of the principal meridians will have their images formed in the same plane.

468. Fig. 227 "represents a pair of eyes in which there is hyperopic astigmatism, either simple or compound. The left eye has its best

Fig. 228.—Unaided Eyes Diagrammed in Figure 227 Would See the Arrow Double as Illustrated Above.

meridian vertical. In this eye, the arrow, held as before, throws its image on the horizontal meridian of the retina, hence in the same plane with it. In the right eye the best meridian is at 135°, as shown by the dotted line. In obedience to the well known law of refraction by curved surfaces, the image of the same arrow must be oblique in this eye, and hence not in the same plane with the object. The obliquity of the image will be greater or less, depending on the quantity of the astigmatism. It is represented as falling on the meridian

170° of the retina. The horizontal image in the left eye and the oblique image in the right eye do not fall on parts of the two retinas that harmonize. The direction of either image in relation to the other cannot be changed except by artificial means—a proper cylindrical lens. This being true, the pair of unaided astigmatic eyes, represented by Fig. 227, must see the arrow double as shown in Fig. 228 unless something is done for the purpose of harmonizing the images."—(*Savage.*)

469. For an inclination of the astigmatic axis of 45° the angle of displacement—i. e., the angle which is formed between the linear object and its image—is practically at its maximum. This angle can be obtained from the formula

$$\tan \theta = \tan \alpha \frac{\frac{1}{h} - \frac{1}{v}}{\frac{1}{z} + \frac{1}{v} + \left(\frac{1}{z} + \frac{1}{h}\right) \tan^2 \alpha}$$

in which the symbols have the following significances:

α = angle which the linear object makes with the principal (horizontal) meridian H having a radius of curvature h.

v = radius of curvature of the vertical meridian, V.

z = distance of the object from the reflecting and refracting surface.

θ = angle which the image of the linear object makes with the direction of the linear object itself.

By assuming that the line object is at infinity, $1/z$ becomes zero and the above formula takes the following simplified form:

$$\tan \theta = \tan \alpha \frac{\left(\frac{1}{h} - \frac{1}{v}\right)}{\frac{1}{v} + \frac{1}{h} \tan^2 \alpha}$$

In this expression h and v being the radii of curvature in the two principal meridians, $\frac{1}{h}$ and $\frac{1}{v}$ represent the refraction of these meridians expressed in diopters. Designating R_h as the refraction of the meridian

of lesser curvature and R_v as the refraction of the meridian of greater curvature, we can write

$$\tan \theta = \tan a \frac{R_v - R_h}{R_v + R_h \tan^2 a}.$$

By assigning to R_h the value of 60 diopters and to R_v, in succession, values of 61, 62, 63, 64 and 65 diopters and to a (angle of astigmatic inclination) successive values of 0°, 15°, 30° and 45° we obtain the following table:

Degree of Astigmatism	*Inclination (a)* (Inclination of object with reference to principal meridian of least curvature)	*Angle (θ)* (Angle formed between the linear object and its retinal image)
1 diopter	0°	0° 0′ 0″
	15°	0° 14′ 8″
	30°	0° 24′ 32″
	45°	0° 28′ 25″
2 diopters	0°	0° 0′ 0″
	15°	0° 27′ 47″
	30°	0° 46′ 28″
	45°	0° 56′ 26″
3 diopters	0°	0° 0′ 0″
	15°	0° 41′ 4″
	30°	1° 11′ 44″
	45°	1° 23′ 50″
4 diopters	0°	0° 0′ 0″
	15°	0° 49′ 40″
	30°	1° 34′ 30″
	45°	1° 50′ 51″
5 diopters	0°	0° 0′ 0″
	15°	1° 6′ 28″
	30°	1° 56′ 36″
	45°	2° 17′ 26″

(Note:—The formulæ quoted above and the accompanying table are taken from the essay entitled Astigmie, by D. E. Sulzer, in Volume 3, *Enclycopédie française d'Ophthalmologie.*)

470. Let us consider for a moment the case of a pair of eyes each having an astigmatism of five diopters, the two principal meridians of minimum curvatures being inclined at 45° on the temporal side in each case (i. e., O. D. 135°, O. S. 45°). An image of a horizontal line formed upon the right retina will make an angle of 2° 17′ 26″ with the object in a certain direction (i. e., either above or below it), while the image formed of the same straight line by the left eye will make an angle of equal amount but in the opposite direction. The two images will, therefore, form an angle of 4° 35′ between themselves. By a superposition of the two images so that they fall on identical

points of the retinas, binocular single vision will ensue. The question arises as to how this can be accomplished. There are, according to Savage, but two ways of accounting for the absence of double vision in such cases as the one detailed above or diagrammed in Fig. 227. Sectional ciliary contraction would account for it; but experimentation shows that, when all ciliary power has been suspended by atropine or by age, the eyes are still able to do something by means of which the double vision is prevented. Such eyes must, therefore, execute rotations about the antero-posterior axes: it is sufficient that the principal meridians of the two eyes shall be parallel, for then all corresponding parts of the two retinal images will fall on identical points of the two retinas. Demands must, therefore, be made upon and met, in large measure, by the oblique muscles in binocular single vision.

In concluding this rather abbreviated presentation on this very important topic we are pleased to quote the following from Savage, together with two plates taken from his *Ophthalmic Myology*.

471. Fig. 229 may be taken for study. "Both eyes have oblique astigmatism of the same kind and quantity. In the right eye the meridian of greatest curvature is at 135° and in the left at 45°. If a rectangular figure be presented to the eyes represented in Fig. 229 it would not be seen with one eye alone or with both together as a rectangle. The rectangle, when held before the right eye in Fig. 229, instead of throwing a rectangular, would throw a non-rectangular, parallelogram image on the right retina; the same rectangle would also throw a non-rectangular parallelogram image on the left retina. The state of refraction of the right eye would make the distorted image lean down and toward the left side, while the distorted image in the left eye would lean down and toward the right side. Cutting off the view of the left eye, the law of direction would have full sway, while the law of corresponding points would be suspended. Since in one eye alone the law of direction is unalterable, all lines of direction must cross in the center of retinal curvature; and the right eye, with the parallelogram image leaning down and to the left, must see the figure casting the image, not as a rectangle, but as a parallelogram leaning down and to the left. Screening the right eye while the left eye looks on the rectangle, it is seen, not as a rectangle, but as a parallelogram leaning down and to the right, the law of direction determining the shape of the figure seen by the left eye, just as it fixed the shape of the figure seen by the right eye. Diagram 1 — 2 — 3 — 4 is what is seen with the right eye alone; diagram 1′ — 2′ — 3′ — 4′ is what is seen by the left eye alone. The moment these two eyes are allowed to look at the rectangular figure, the law of correspond-

ing retinal points is brought into conflict with the law of direction, and the latter is modified by the former. There is no necessity for

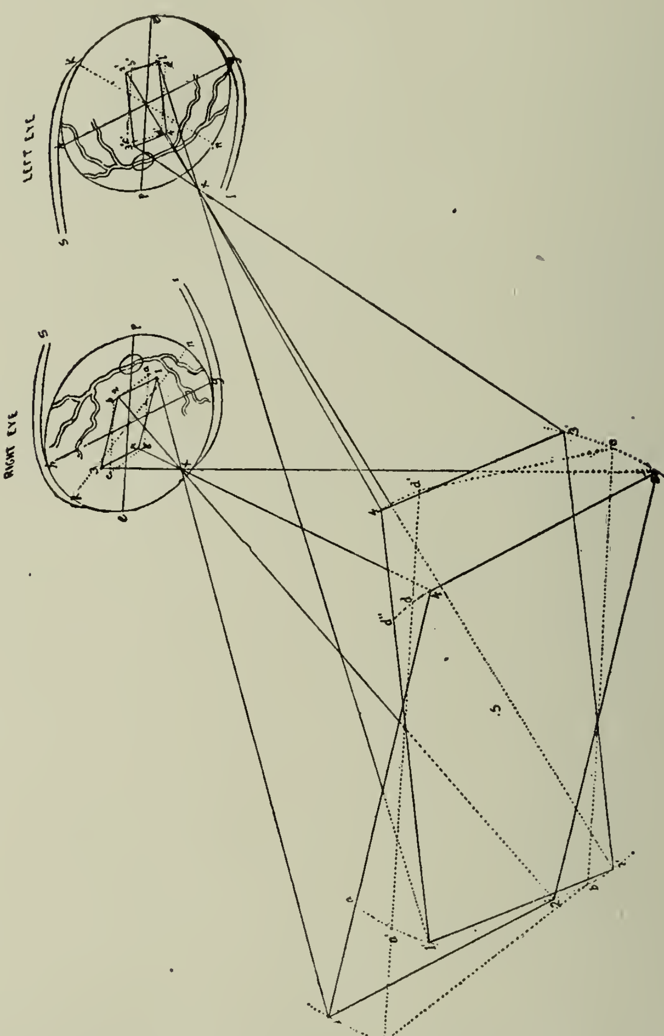


Fig. 229.—Showing the Retinal Images in Non-parallel Oblique Astigmatism. (After Savage.)

changing the visual axes when looking at the rectangle with these two eyes; but, unless some change is effected in some way, each eye would see its own parallelogram leaning down and toward the opposite side. Instantly a change does take place in both eyes, so that the two see

together, not a rectangle nor a parallelogram, but a trapezoid with the longer side above. A clear understanding of what this change is and how it is effected may be had by a further study of Fig. 229. In the right eye is shown a dotted parallelogram *abcd* of precisely the same form as the parallelogram image 1 — 2 — 3 — 4: but in the former the upper and lower lines are parallel with the horizontal meridian. In the left eye also is shown a dotted parallelogram *a′b′c′d′* of the same form as the parallelogram 1′ — 2′ — 3′ — 4′, with its upper and lower lines parallel with the horizontal meridian of this eye. The line *cb* in the right eye bears throughout the same relation to the macula, the horizontal and vertical meridians of this eye, that the line *c′b′* does to the same parts of the left eye, and they, therefore, correspond. The greater part of the line *da* in the right eye also corresponds with the greater part of the line *d′a′* in the left eye, the parts of these lines not corresponding being their extremities. But the line *cd* in the right eye nowhere corresponds with the line *c′d′* in the left eye, except at the points of beginning above; and the same is true of lines *ba* and *b′a′*, in their respective eyes. If the dotted parallelograms could be made to coincide with the parallelogram images, the result would be that the two eyes together would see the figure *abcd′*, a trapezoid, with the longer side above. How this is effected is shown in Fig. 230, where each eye has been revolved on its visual axis by its superior oblique muscle, so that the horizontal meridian is made parallel with the upper and lower borders of the parallelogram image; and thus, as far as possible, corresponding parts of the two retinas are brought under the two dissimilar images, and the figure seen binocularly is *abcd′*. The part of the trapezoid seen in common by the two eyes is *a′bcd*, the part seen by the right eye alone is *aba′*, and that seen by the left eye alone is *dcd′*. As will be seen, the law of corresponding points has so modified the law of projection that the visual lines no longer have a common crossing point. This is anarchy, so far as projection is concerned, in these eyes."

472. "When the law of direction is interfered with, as a result of the conflict between it and the more imperious law of corresponding retinal points, the object seen is always in the position that it would have been in, had the images primarily fallen on the parts of the two retinas that have been rotated under them, in obedience to the supreme law of binocular single vision—the law of corresponding retinal points. The displaced images, as a result of either natural or artificial means, cover areas of the two retinas that do not correspond. In order to have binocular single vision, retinal areas that more nearly correspond, and are of the same shape and size as the images, must be brought

under them. The object will be seen as though no rotation had taken place, as if the images had primarily fallen on these parts, in perfect

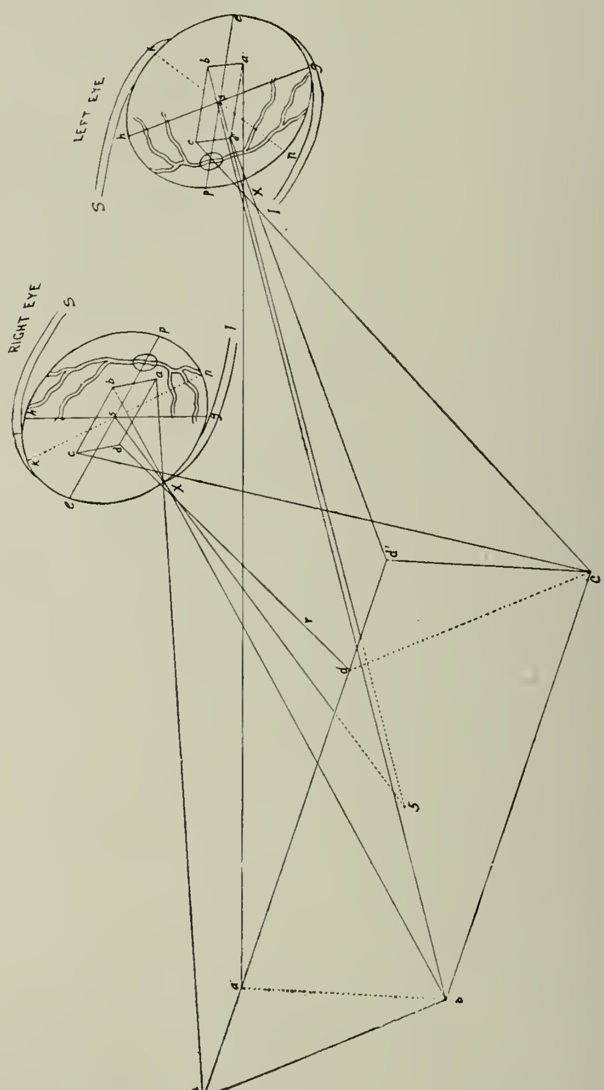


Fig. 230.—The Retinal Images in Certain Instances of Non-parallel Oblique Astigmatism. (After Savage.)

obedience to the law of projection, although the lines of direction drawn from the images to the single object will not cross at the center of retinal curvature. In cases of decentration of the maculas, and in

displaced images by means of prisms, all lines of direction will cross at one point, but that point will be above, below, to the outer or inner side of the true point; while in oblique astigmatism, and when the axes of correcting cylinders are displaced, no three lines of direction cross at the same point.''

473. ''Imperfect as is binocular single vision in uncorrected oblique astigmatism, the meridians of greatest curvature either diverging or converging above, it could be effected in no other way than by a revolution of the eyes by the symmetric harmonious action of the oblique muscles. It is true that Nature has one other method of preventing diplopia—namely, mental suppression of one of the displaced images. It may be that amblyopia resulting from oblique astigmatism high in degree, and from insufficiency of the obliques, is more common than one would at first think. Certainly, if the obliques cannot do their proper work in effecting binocular single vision, in the first years of life, nothing is more reasonable than to suppose that amblopia *ex anopsia* would develop.''

XXVIII. CHIASMAL IMAGES

474. In 1914 C. F. Prentice, M. E., presented in the pages of *The Ophthalmic Record* a paper entitled The Prism-dioptry Establishes a Dimensional Unit at the Optic Chiasm. In this essay he postulates the hypothesis of a *chiasmal image* which, as Casey Wood says, ''is new and if accepted will be a real addition to the subject, but some of us will find it difficult to accept it, not only because it is difficult to conceive of an image anywhere obtained except at the primary sensitive-plate of the retina, where it is (physically) formed, or within the central area about the calcarine fissure where it is (psychically) interpreted: . . . but we know that there are other neuronic points and areas within the cranium that greatly influence the character of the visual image, and as there is no valid reason why one should conceive of image-formation at any point along the optic radiational lines, the concept of a conjoint image within the chiasma is not only a thinkable but a useful idea.'' No better or briefer presentation of this subject can be made than that given by Prentice (see this *Encyclopedia*, Vol. III, pages 2047-2055; Vol. VIII, pages 6170-6172 and Vol. X, pages 7296-7302.

475. ''In *physiologic optics*, the chiasmal image is a strictly figurative image consisting of that orderly assemblage of the optic nerve fibrils, within the cross sectional and comparatively small area of the optic chiasm, which receive their individual stimuli from corresponding points in each retinal image. Of course, this also implies that the

supposed chiasmal image should be proportionately smaller than the retinal images, in order that they may appear in their entirety within the more circumscribed area of the chiasm. However, this may remain a matter of conjecture, and is quite immaterial, when merely comparing the positions of the images projected from the retinæ into the parallel area of the optic commissure, and that may or may not there constitute a *single* chiasmal image of the size conceived by the brain,

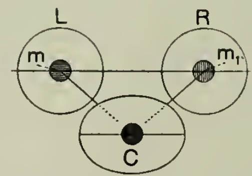


Fig. 231.—Chiasmal Image. (After Prentice.)

in either orthophoric (orthoscopic) or heterophoric vision, respectively. Therefore, the *figurative* chiasmal image may be safely accepted, since it, at least, makes it easy to produce diagrams in which the retinal images and the image conceived by the brain are separately pictured to illustrate the phenomenon of binocular vision. With this conception of the chiasmal image, orthoscopic binocular vision may be said to require absolute equality in the dimensions of the retinal images, in order that these identical images, when conveyed by the optic nerves,

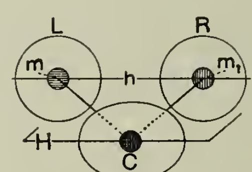


Fig. 232.—Chiasmal Image. (After Prentice.)

may exactly cover each other at the optic chiasm. In other words, the axial image-points m and m_1, Fig. 231, being separately transmitted by their respective optic-nerve fibrils, must exactly cover each other at the center C of the chiasmal image, which is, therefore, of two-fold light and shade intensity, provided that the light and color perceptions, respectively, are the same for each eye. In Fig. 231 this increased intensity of the chiasmal image at C is graphically illustrated, being achieved in the drawing through superposition of the vertical and horizontal shadings used respectively to distinguish the right and left retinal images in R and L from each other."

476. "This single chiasmal image at C corresponds to that equipoise of the extrinsic ocular muscles which is associated with the normal directions of both visual axes, called orthophoria. In fact, it is that condition in which the centers m, m_1 and C of their respective images are all located in the same horizontal plane hH, thereby insuring a common horizon for them as shown in Fig. 232. Therefore, the chiasmal horizon, in the absence of a better term, may be said to be the horizontal diameter of the chiasmal field in whose center C are located the superposed chiasmal images transmitted from the macular centers m and m_1, the foveæ of both eyes. In fact, as will be later shown, the axial image-points m and m_1, the centers of the maculæ, are always projected to the center of the chiasmal field, C, regardless of the directions of the visual axes. It is evident that a faulty projection of the visual axes, such as in hyperphoria, for instance, will cause a change in the elevation of at least one of the axial image-points, m, m_1, with respect to a common horizon H, thus creating two vertically displaced

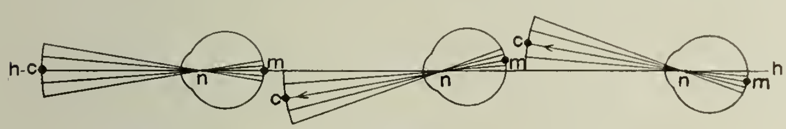


Fig. 233. Fig. 234. Fig. 235.
Chiasmal Images.

images of the same object somewhere within the field of the optic chiasm. In order to become familiar with the location of such dual chiasmal images it is necessary first to determine the positions of their corresponding retinal images. A fundamental law in physiologic optics teaches that the center of the object and the center of the image are in line with the nodal-points of the eye; in other words, the center of the object, the nodal points and the macular center are points upon the same line, the visual axis, located in a plane coincident with, or that may be inclined to, the horizon. In the following diagrams the single nodal point of Donders' reduced eye is applied."

"In Fig. 233, the visual axis cm is coincident with the horizontal plane hh. In. Fig. 234, the visual axis cm is directed below, whereas, in Fig. 235 it is directed above the horizontal plane hh."

477. "In each of these figures the visual axis is directed to the center c of its own object-space, irrespective of the dimensions of the object that may be located upon the horizon, so that the visual axis may also be said to be a line connecting the center c of the object-space with the center m of the image-space. Therefore, each change in the direction

of the visual axis merely establishes a new center c in the object-space of the deviating eye which is in line with the fovea m, the center of the image-space. In short, for the deviating eye, Fig. 237, D is the displacement of the visual axis cm_1 from the object-center O, whereas d is the corresponding displacement of the fovea m_1 from the image-center I_1."

"It is here proposed to confine the discussion to hyperphoria, be-

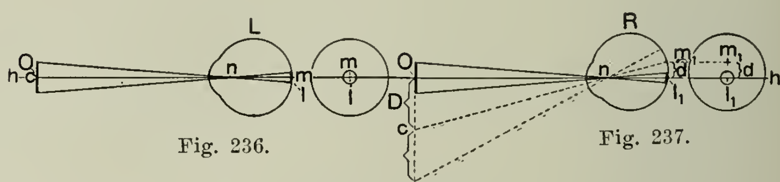


Fig. 236.

Fig. 237.

Chiasmal Images.

cause it may be more effectually counteracted through the use of prisms than any other muscular imbalance. For convenience, the left eye, Fig. 236, is pictured from the temporal side with its visual axis cm horizontal; therefore, the centers of the object O and its retinal image I are located in the plane of the horizon. The right eye is shown in Fig. 237, from the nasal side, with its visual axis cm_1 in the object-space below the horizon; wherefore, the center of the same object O is above the visual axis cm_1, and the center of the image I_1 is correspondingly

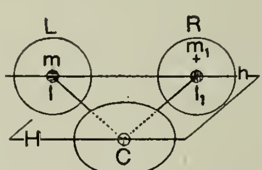


Fig. 238.—Chiasmal Image. (After Prentice.)

below it at a distance d from the fovea m_1. Comparison of the figures shows that the centers of the retinal images I and I_1 in both eyes are located in the same horizontal plane hh, but that they occupy quite different positions with respect to their associated axial image-points, m and m_1. The fovea m of the left eye and the center of its retinal image I are coincident, whereas, in the right eye its retinal image-center I_1 is below the fovea m_1. Moreover, it is quite evident that there would not be any consciousness of a difference in the elevations of the retinal images, I and I_1, if they were transmitted by the optic nerves

to the chiasm in the same horizontal plane *hH,* as shown in the *incorrect* Fig. 238. That two images are produced which effect consciousness of a difference in their elevations with respect to a common horizon H is proof that the phenomenon must be explained through the associated functions of the optic nerves and the chiasm. In fact, this consciousness of two images can only be accounted for by the assumption that the axial image-point of each eye at the macula is conveyed by its

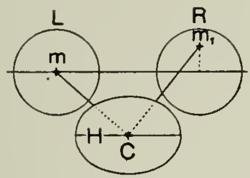


Fig. 239.—Chiasmal Image. (After Prentice.)

corresponding optic-nerve fibril to the center of the chiasmal field. In other words, both macular centers m and m_1 are transmitted by their respective nerve fibrils so as to produce superposed images of themselves at the center C of the chiasm, Fig. 239, regardless of any deviation that may exist between the visual axes.''

478. ''Such being the case, the center m of the retinal image I, when transmitted through the left optic nerve by its macular fibril mC, Fig. 240, is located in the center C of the chiasm upon the chiasmal horizon

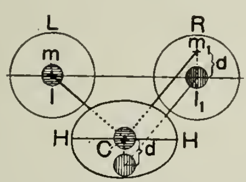


Fig. 240.—Chiasmal Image. (After Prentice.)

HH; whereas, the center I_1 of the retinal image in the right eye is conveyed along the right optic nerve below the macular fibril of m_1 to a point at the same distance d below the chiasmal center C. In short, the vertical separation of the chiasmal image-centers is equal to the distance d between the macular center m_1 and the center I_1 of the image in the deviating eye. It is further evident that, if the vertical displacement d of the fovea m_1 in the deviating eye is greater than or equal to the diameter of the retinal image itself, two separated chiasmal images are formed, Fig. 241 and Fig. 242; whereas, if the displacement

of the fovea m_1 in the deviating eye is less than the diameter of its retinal image, two eccentrically superposed chiasmal images are produced, Fig. 243. Therefore, the nature of these dual images, as to whether they are separated or overlap, depends upon the proportion of the displacement d of the fovea m_1 in the deviating eye to the diameter of its retinal image I_1 centered in the horizontal plane h."

479. "Moreover the foveal displacement d and the diameter of the retinal image may both be determined, provided the distance of the nodal point from the retina is known. For example, Donders' reduced eye being chosen, and in which the distance between the nodal point

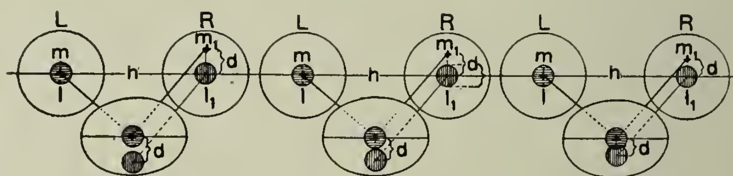


Fig. 241. Fig. 242. Fig. 243.
Chiasmal Images. (After Prentice.)

and the retina is equal to 15 mm., or 1.5 cm., it is apparent from Fig. 244 that:

$\frac{d}{1.5} = \frac{D}{100} \therefore d = \frac{1.5D}{100}$, in which D is a dimension in the tangent plane Oc at a distance of 100 cm. from the nodal point n. Therefore, D is synonymous with the prism-dioptry when it is made equal to 1 cm., and, if introduced in the above equation, gives $d = \frac{1.5}{100} = 0.015$ cm., or 0.15 mm. as the separation of the chiasmal image-centers for a deviation of the visual axes corresponding to 1 prism-dioptry. The above equation also proves that:

"In manifest hyperphoria of 1 prism-dioptry the distance between the chiasmal image-centers is equal to one hundredth part of the distance between the nodal point and the retina in the deviating eye. It is also apparent that the separation of the chiasmal image-centers will increase in proportion to the deviation between the visual axes, wherefore, 1^Δ 2^Δ 3^Δ 4^Δ of deviation between the visual axes correspondingly produce 0.15 0.3 0.45 0.6 mm. separation of the chiasmal image-centers. It is next necessary to determine the size of the retinal images, in order to ascertain if the chiasmal images are separated or overlap for a particular deviation of the visual axes."

480. "As the size of the retinal image depends upon the size of the object, it is convenient to select as the object one of the small letters that represent the conventional unit of visual acuity in Snellen's test types, and whose vertical and horizontal dimensions are embraced by the visual angle of 5 minutes. Therefore, the height of this object corresponds to the tangent of 5′, which, if computed at a distance of 1 meter, is 0.001455 M., or 1.455 mm.; consequently, the object-letter is

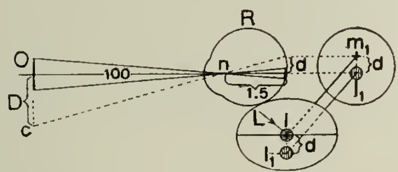


Fig. 244.—Chiasmal Image. (After Prentice.)

8.73 mm. square, at 6 meters, the distance at which the type is used. Incidentally it may be stated that this dimension is rarely exactly reproduced in modern editions of Test Types, and which are often found to be correspondingly faulty in all of the letters. The size of the retinal image, *I*, produced by a letter 8.73 mm. square, when placed at 6 meters from the reduced eye, may be deduced from Fig. 245 as follows:

$$\frac{I}{15} = \frac{8.73}{6000} \therefore I = \frac{15 \times 8.73}{6000} = 0.02182 \text{ mm., which is such a minute}$$

dimension that, even if mechanically reproduced for inspection, it

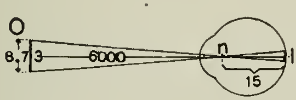


Fig. 245.—Size of Retinal Image.

could scarcely be differentiated by the eye without the use of a microscope. As $1^{\triangle}$ is known to produce a separation of the chiasmal image-centers equal to 0.15 mm., and the vertical dimension of the retinal image in the deviating eye of normal visual acuity is 0.02182 mm., it follows that the dual chiasmal images are separated, since $d = 0.15$ mm. is greater than *I* or $v_1 = 0.02182$ mm. In order that the dual chiasmal images may just touch each other peripherally, the diameter of the image *I* would have to be equal to $d = 0.15$ mm. This value for *I* being introduced in the equation $\frac{O}{I} = \frac{6000}{15}$ gives the diameter of the

object $O = \dfrac{0.15 \times 6000}{15} = 60$ mm., which is also the value of the prism-dioptry at 6 meters distance."

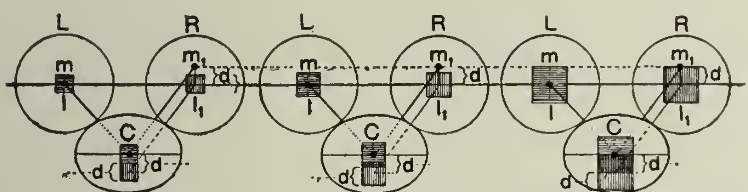
481. "Reference to the adjoining chart of letters shows that 60 mm. is the dimension of a letter which should be interpolated between *E* and *T*. In other words, all of the letters between *T* and *L*, when viewed at

VISUAL ANGLE 5′

Distance		Height	
60 M.	**E**	87.3	mm.
		60	mm.
36 M.	**T**	52.38	mm.
24 M.	**D**	34.92	mm.
18 M.	**P**	26.19	mm.
12 M.	**F**	17.46	mm.
9 M.	**O**	13.095	mm.
6 M.	**L**	8.73	mm.
1 M.	**H**	1.455	mm.
⅓ M.	**V**	0.485	mm.

a distance of 6 meters, produce separated chiasmal images for a manifest hyperphoria of $1^{\triangle}$; whereas, letters or objects which are larger than 60 mm. in height will produce vertically overlapped chiasmal images whose centers are uniformly 0.15 mm. apart. Separated chiasmal images also apply to type held at the reading distance whenever the letters are smaller than the prism-dioptral deviation between the visual axes in the object-space. For instance, in the accompanying chart the letter *v* is 0.485 mm. high at 1/3 M., whereas the prism-dioptral devia-

tion at this distance is 1/3 of a centimeter, or 3.33 mm. This deviation, being considerably greater than the vertical dimension of the letter *v* in the object-space, will naturally cause visual confusion, through making a printed line of the same kind of type appear to be projected from the position of the line next following when the consecutive lines of type are 3.33 mm. apart. For this reason hyperphoric subjects of $1^{\triangle}$, even with normal retinal perception in each eye, can not read very small type, nor without great difficulty even ordinary type, and frequently complain of a sense of uncertainty in following the lines of a printed page. The limits between which overlapped images are produced is made apparent in the following necessarily exaggerated diagrams, in which the dimensions of the various retinal images have been calculated for white square targets of different sizes placed at 6



Figs. 246, 247, 248.—Deviation Between the Visual Axes Equals 1 Prism. Dioptry. Foveal Displacement, Separation of the Chiasmal Image-Centers and the Image-Extension = d = 0.15 mm. for Donders' Reduced Eye.

Fig. 246.—Object 60 mm. sq. Image 0.15 mm. sq.

Fig. 247.—Object 87.3 mm. sq. Image 0.2185 mm. sq.

Fig. 248.—Object 120 mm. sq. Image 0.3 mm. sq.

meters distance. In Fig. 246 the retinal images are 0.15 mm. square, which, being equal to the foveal displacement corresponding to $1^{\triangle}$, not only shows the chiasmal images to be peripherally in contact, but also that the chiasmal image for the left eye is extended below its horizon by an amount equal to the height of the chiasmal image for the right eye, thus producing a vertically elongated picture of the square target that is twice the height of the normal image conceived in orthoscopic binocular vision.''

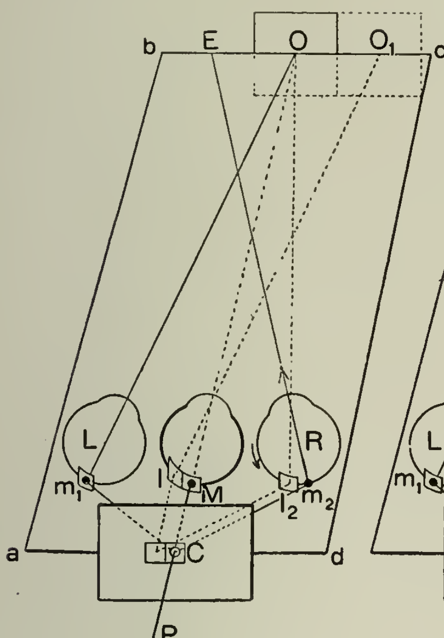
482. ''The retinal image in Fig. 247 is 0.2185 mm. square, and being larger than the foveal displacement, shows the chiasmal images to overlap. In fact, as the retinal images proportionately increase in size for larger objects placed at a fixed distance, so will the chiasmal images increase and invade each other vertically from their respective fixed centers. Fig. 248 represents a still larger image, 0.3 mm. square, demonstrating that the chiasmal images overlap each other by one-half.

Furthermore, in all of these diagrams it is made apparent that the foveal displacement, the separation of the chiasmal image-centers and the extension of the normal image are one and the same linear dimension. Therefore, it has been conclusively demonstrated that for each prism-dioptry of deviation between the visual axes there is a separation of the dual chiasmal image-centers equal to 0.15 mm.*; that the chiasmal images are separated when the retinal images are smaller than the foveal displacement, and that the images overlap when their retinal images are larger than the foveal displacement in the deviating eye. Recalling that the prism-dioptral deviation between the visual axes in the object-space bears the same proportion to the size of the object itself as the foveal displacement to the retinal image in the deviating eye, it is also to be understood that the chiasmal images are vertically separated when the size of the object viewed binocularly is less than the prism-dioptral deviation, and that they overlap when the object viewed is greater than the prism-dioptral deviation between the visual axes. In short, when the diameter of the object at 6 meters' distance is exactly equal to the prism-dioptral deviation between the visual axes, contiguous chiasmal images are formed whose line of contact is the boundary between separated and overlapped images.''

483. These images can be shown ''to serve a useful working hypothesis in making a lucid drawing to illustrate the phorias, and as a figure of speech when attempting to differentiate between the ocular images and the corresponding brain-images: also as a figure of speech, since it is just as imaginary as its correlative chiasmal image, which, at least figuratively, occupies a more definite location. Moreover, the chiasmal image is quite as conceivable as the all permanent ether through which light is supposed to be propagated. In order to demonstrate the purpose and need of at least one point of orientation, although two different ones will be here jointly applied, let it be supposed that the diagram, Fig. 249, represents a horizontal plane, *abcd,* in which the corresponding sections of the right eye, R, and the left eye, L, are located to view the object, *O,* upon the median line, *MO.* It is also assumed that the visual axis of the right eye, R, is faultily directed towards *E*, as in esophoria, so that its macula, m_2, is turned to the right: whereas, the macula, m_1, of the left eye, L, retains its normal position with respect to the object, *O;* and, therefore, also with respect to the center, *C,* of the chiasmal field and the macula, *M,* of the mean eye on the median line, and to which points of orientation the macular center, m_2, in the right eye is also projected. Consequently, the macular centers, m_1 and m_2, in both eyes have the same points of orientation, *C*

* Donders' reduced eye, whose first principal focal length F′ is 15 mm.

and M, in common, while the image-center, m_1, of the left eye alone is transmitted to these points. But the center of the image I_2, projected from O into the right eye, is situated on the left side of the macula, m_2, and is, therefore, transmitted with equal displacement so as to be located on the left side of the centers of orientation, C and M, in the chiasmal field and mean eye, respectively. Therefore, the displaced image, I_2, in the right eye, is transmitted to and located on the left side of the



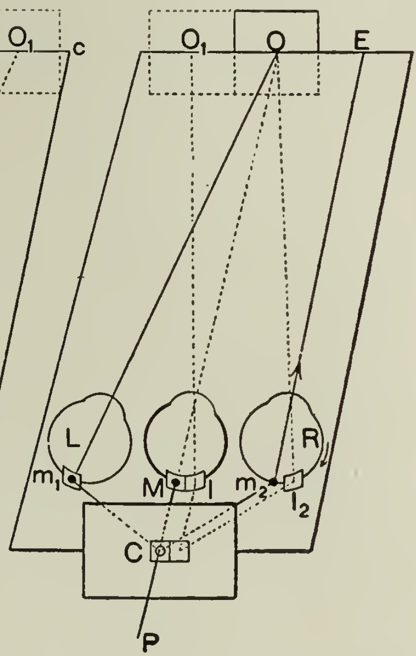


Fig. 249.—Homonymous Projection (After Prentice). Contiguous mean cyclopean image.

Fig. 250.—Heteronymous Projection (After Prentice). Derived from chiasmal images.

mean eye as the false cyclopean image I: and it is this image, belonging to the right eye, that is homonymously projected to O_1, on the right side of and at the same prism-dioptral distance, EO, from the object O. The points m_1, m_2, C and M are corresponding points with reference to the axis, PCM, of bilateral symmetry within the cranium, which coincides with the median line, MO, in the object-space and is directed to the supposed center, P, of image-perception in the brain.''

484. In Fig. 250 ''heteronymous projection of the ocular images is illustrated. Both diagrams show that the chiasmal and mean cyclopean

images, respectively, are contiguous, because the horizontal diameter of the object is made equal to the prism-dioptral deflection, *EO,* so that the real object, *O,* and the mentally conceived object O_1, are also in contact.''

''The figurative mean cyclopean images, *I* and *M,* are graphically projected from their corresponding chiasmal images, so that conjointly they make it possible to pictorially illustrate either homonymous or heteronymous diplopia in a manner not hitherto lucidly accomplished. In view of the indeterminate pyschophysical character of these images, and an effort made to picture them in a drawing, the delineator will at least need to assume that the center, *P,* of the so-called brain-image is the center of image-perception; that it is located in the horizontal plane, in juxtaposition to the center, *M,* of the centered cyclopean image of the object on the median line and, therefore, coincident with the center of the chiasmal image· said line, *PCM,* within the cranium, being considered the axis of visual orientation, or the directrix of bilateral symmetry of vision in the mind at least of the draftsman.''

—(C. S.)

Physiologic excavation of the optic nerve-head. See p. 4787, Vol. VI of this *Encyclopedia.*

Physostigma. Ordeal nut. Chop nut. Split nut. A genus of tropical leguminous plants; also the poisonous seed of *physostigma venenosum,* Calabar bean, a climbing plant of Africa, contains the alkaloids physostigmin and calabarin. Physostigma is a motor depressant, miotic, and antispasmodic, in large doses producing death by paralysis of respiration. It is employed in tetanus, trismus, and other spasmodic affections; as an expectorant in bronchitis, asthma, and emphysema, and as a stimulant in atonic constipation and dilatation of the stomach. Dose of extract, $\frac{1}{16}$ — $\frac{1}{6}$ gr. (0.004-0.01 gm.); of fluid extract, 1-3 min. (0.066-0.2 cc.); of tincture, 5-15 min. (0.333-1 cc.).

A 1:15 glycerin solution of the alcoholic extract is by some preferred to any of the miotic alkaloidal solutions.

Physostigmin. The correct pharmacal (U. S. P., B. P., etc.) name for eserin. See p. 4521, Vol. VI of this *Encyclopedia.*

Phytolacca. A genus of plants of many species, mostly poisonous. The fruit of *phytolacca decandra,* ''poke'' or ''skoke,'' also the root of the same (*phytolaccæ radix*) have been used in granular conjunctivitis.

Phytolacca decandra. Pigeon-berry. The berries and root (official in U. S. P.) have been used in granular conjunctivitis.

Pialscheide. (G.) Pial sheath.

Pia mater. The innermost and most vascular of the three membranes of the brain and the spinal cord.

Pian. Yaws. See **Eyelids, Frambesia of the.**

Picha, Joseph. A celebrated Viennese military surgeon and ophthalmologist. The date and place of his birth are not known. His medical education, however, was received at the Medico-Chirurgical Josephs Academy at Vienna. In 1863 he was upper physician in the Austrian army, which he accompanied on the expeditions of 1864 and 1866. In the last named year he became assistant to Stellwag von Carion at the Josephs Academy. He was placed at the head of the eye department of Garrison Hospital No. 1, at Vienna, and there remained for nine years. Having held a number of other official positions, he died Mar. 17, 1886, aged only 47. He was a man of great earnestness and beauty of character.

Picha's chief ophthalmologic writing was a work entitled "*Gemeinfassliche Darstellung der Refractionsanomalien, mit Rücksicht auf Assentirung und Superarbitirung.*" This excellent treatise was crowned with the Brendl prize, and in 1874 was adopted as the official work upon its subject in the Austrian army.—(T. H. S.)

Pickard, William. A famous blind lawyer. The place and date of his birth are both unknown. In 1808, however, he was blinded by a gunshot wound. He was admitted as an attorney at the Court of Queen's Bench, before Mr. Justice Bayley, and then began to practise as a solicitor at Wakefield. He was very successful in every branch of the law. He never married. He died in 1836 or '37.—(T. H. S.)

Pickering, Edward Charles (1846—). Born in Boston, Mass., he graduated from the Lawrence Scientific School, Harvard (1865), where he taught mathematics (1865-67). In 1867-76 he was Thayer professor of physics in the Massachusetts Institute of Technology, and since then professor of astronomy and director of the Harvard College observatory. He established the first physical laboratory in the United States, made a special study of the light and spectra of the stars, and devised the meridian photometer with which he made nearly a million and a half measures of the light of the stars. With four telescopes, two at Cambridge, Mass., and two at Arequipa, in Peru, he made observations in both the Northern and Southern hemispheres, and secured over 200,000 photographs of the stars. His researches yielded many important discoveries, and he was a leading authority on the subject of stellar spectroscopy. He was awarded several medals for astronomical work, and was a member of many important scientific societies in Europe and America. His publications include *Elements of Physical Manipulation* (2 parts, 1873-76), and he edited *The Theory of Color in its Relation to Art,* by Bezold (1876). (*Standard Encyclopedia.*)

Picric acid. This substance appears in the form of pale-yellow crystal-

line scales. It is obtained by the action of nitric acid on phenolsulfonic acid. Picric acid is easily soluble in hot, but only slightly in cold, water. It is also soluble in alcohol and ether. Its taste is intensely bitter, and its tinctorial power is very great, the solutions of it having a strong-yellow color. It has been much used for dyeing silk, wool and leather. As it does not adhere by itself to vegetable fiber, it serves for a test to distinguish cotton from wool or silk. The salts of picric acid are a very important ingredient in explosives. It was formerly called *carbazotic acid*. See, also, **Acid, Picric,** p. 72, Vol. I of this *Encyclopedia.*

Picrinic acid. See **Acid, Picric.**

Picture-lens. A long-focus lens used for examining pictures.

The Zeiss lens consists of a single meniscus of a special form to remove defects in the image due to the astigmatism of oblique pencils, thus enabling a person looking through the glasses to see clearly points situated away from the center of the picture.

Zeiss Picture Lens.

The lens is contained in a simple mount having a wooden handle attached to it. The lens mount is fitted with a readily detachable ebonite cup shaped to fit the rim of the eye.

To place the viewer in its best position in front of the eye the cup should be turned and so held that it may snugly fit the rim of the eye. This ensures also that the lens will occupy an accurately central position in front of the eye.

Piebald iris. See **Chromatic asymmetry.**

Pierd'houy, Augusto. A distinguished Italian ophthalmolgist, who died very young. Born in 1854, he became a pupil of Quaglino. He founded the eye-division of the Milan Polyclinick, and was one of the collaborators on the *Annali di Ottalmologia*. He died in 1886, aged 34.—(T. H. S.)

Pieringer, Joseph. A distinguished Austrian ophthalmologist. Born Mar. 31, 1800, at Kleinzell, Upper Austria, he received his medical degree in Vienna, and, turning attention to ophthalmology, became assistant first to Jaeger, then to Rosas. In 1828 he removed to Gratz, in order to accept the chair of ophthalmology in the University at that

place. Here he taught and practised until 1860. He died Sept. 22, 1879, aged 79.

According to Hirschberg, "Aside from several essays and popular writings he left but one sole offspring of his intellect—but that was a lion." The title of this work was "*Die Blennorrhöe am Menschlichen Auge; eine von dem deutschen Aerztlichen Vereine in St. Petersburg gekrönte Preisschrift*" (Gratz, 1841). In this work the author arrives at several important conclusions. These, freely re-stated, are: (1) That gonorrheal ophthalmia occurs simply and solely as the result of conveyance to the eye of the gonorrheal secretion from other parts. (2) This secretion is contagious for the human eye, but not for the eyes of animals. (3) Blennorrhea of high degree is not dangerous but beneficial to eyes afflicted with pannus. (4) Inoculation with gonorrheal secretion should be resorted to only when both of the patient's eyes are afflicted with pannus, for, otherwise, the healthy eye is easily infected from its fellow, and will then almost certainly be lost. (5) The prompt washing out of an eye to which the gonorrheal virus has been conveyed will prevent the development of the affection of that eye. (6) This is as true of the eyes of the newly-born as of any others.

Though absolute priority for any of these conclusions can hardly be claimed for Pieringer, yet it must at least be granted that he first of all made a sufficient series of determinate experiments to place them on a solid and lasting foundation. But for him the Credé solution might never have been introduced.—(T. H. S.)

Piezometer. PIESIMETER. PIESOMETER. An instrument for testing the sensitiveness of the skin to pressure.

Hale's piesimeter consists of a glass tube inserted into an artery for the purpose of ascertaining the blood-pressure by the height to which the blood rises in the tube.

In quite another sense is this term applied to an instrument devised to determine the compressibility of the eye in the orbit. Guttman (*Zeitschr. f. Augenh.*, April-May, 1914) in his researches finds that in high-grade myopia the capacity of the globe of being pushed back into the orbit by a weight of 25 grammes is diminished 0.3 to 0.4 millimeters in comparison with that of the emmetropic eye. In a few cases of axis myopia there is a tendency to greater compressibility into the orbit (2.0 to 3.0 millimeters) as well as greater mobility for rapid and unlimited changes in direction, on account of extraorbital protrusion, whereby the posterior segment of the globe attains a greater mobility.

Pigment, Absence of. ALBINISM. See p. 204, Vol. I of this *Encyclopedia;* also **Hereditary diseases of the eye.**

Col. Woodruff (*Ophthalmic Year-Book*, p. 28, 1909) has urged that

lack of pigment with excessive exposure to light may cause many eye diseases as well as consumption and neurasthenia. He asks that ophthalmologists should note in each case the pigmentation of the skin, hair, and different parts of the eye. He believes that blondes are more liable to suffer from various pathological conditions that might thus be traced to their cause from deficient pigmentation.

Pigment. Any normal or abnormal coloring-matter deposited in the body.

Pigmentation, Ocular. Coloration or discoloration of various ocular tissues or parts by the deposition in them of coloring-matter—endogenous or extraneous—has been to some extent treated under several headings, especially on p. 2946, Vol. IV, of this *Encyclopedia.* Other references are the following, taken in anatomical order.

Pigmentation of the eye in general. Augstein (*Klin. Monatsbl. f. Augenheilkunde,* Jan., 1912) enumerates the situations in which pigment can be observed in the anterior part of the eye during life, and the circumstances under which it occurs.

Pigment particles may be found in the conjunctiva bulbi, with or without similar particles in the cornea, after injury, in connection with relapsing vitreous hemorrhage, and after cataract extraction. This pigment is hematogenous. Two factors are necessary for its appearance, extravasation of blood and the presence of some free uveal pigment cells. The latter, according to the author, construct the deposited pigment out of the hemoglobin of the extravasated blood. Pigment rings may frequently be noted surrounding the scleral veins at their point of exit in the ciliary region. This form of conjunctival pigmentation is physiological, but not congenital. The earliest appearance is about the age of six months, and it becomes increasingly common in later life. It is most common in old persons and in brunettes. After inflammation in the uveal tract, these pigment rings become more pronounced, and new pigment develops in their neighborhood. This is to be attributed to the wandering of uveal pigment.

Pigmentation of the cornea may be in or below the epithelium, in the corneal substance, and on or beneath Descemet's membrane. It has been found under the epithelium after healing of a corneal ulcer which had been cauterized, and after a burn of the cornea, in both cases without vessel formation. Pigment deposits on Descemet's membrane were observed in one case after removal of traumatic cataract, no inflammation having occurred. They are often seen after prolonged use of miotics in glaucoma, and are believed to be attributable to the miotic. Another form of corneal pigmentation is that associated with the vessels left in front of Descemet's membrane after an attack of keratitis

parenchymatosa, or iridocyclitis. Pigmentation is also sometimes the result of a contusion. Melanosis corneæ is a condition sui generis, and is congenital. It has, in the author's opinion, nothing to do with membrana pupillaris perseverans.

Augstein has observed in the majority of cases submitted to iridectomy or extraction of cataract, fine specks of pigment scattered over the anterior surface of the iris, especially in its lower half. They first appear two or three weeks after operation. A similar condition has been observed after a contusion, and following a perforation of the cornea. Deposits of pigment on the iris after iritis are less common. (A. J. Ballantyne, *Ophthalmoscope,* p. 487, Aug., 1914.) See, also, p. 5020, Vol. VII of this *Encyclopedia.*

Pigmentation of the eyelid. See p. 5020, Vol. VII of this *Encyclopedia.* This sign, although not constant, has been observed by several clinicians as occurring in the upper lid in exophthalmic goitre. The discoloration is a light-brown, such as seen in Addison's disease.

Pigmented patches of the conjunctiva. These are described on p. 3054, Vol. IV of this *Encyclopedia.* It may be added here that Anselmi (*Archivio di Ottal.,* p. 347, 1914) has noted this peculiar condition in a man of 32 who came for a slight degree of toxic neuritis from alcohol and tobacco. In other respects his eyes had always been free from internal or external disease, and he had never used collyria. On the tarsal conjunctiva of each upper lid was an irregularly-rounded, gray area about five or six millimeters in diameter. These areas were smooth, not raised above the surrounding conjunctiva, and of fairly well-defined outline. The Meibomian tubules could be seen in the usual fashion through the palpebral conjunctiva, except within the gray areas. A piece was removed from the affected area of each upper lid and studied in microscopic sections. In neither specimen was there any actual pigmentation. As regards the right side, the dark color was due to a large cystic cavity occupying the whole thickness of the tarsus. In the tissue from the left side there were numerous large cystic cavities in the tarsus. The spaces were lined with epithelium. The formation of the cysts appeared from the histologic examination to be due to modifications in the epithelial elements of the glands and their ducts, leading to their transformation into sebaceous cells. The process had apparently originated in the excretory portions of the glands.

Pigmentation of the cornea. See **Cornea, Melanosis of the,** p. 3400, Vol. V of this *Encyclopedia,* where this condition is fully considered. To the material presented there may be added the more recent case of P. J. Waardenburg (*Tydschr. v. Geneesk.,* Feb. 27, 1915), who discovered in a patient's eyes a pigmentation of both corneæ and very fine

peripheral opacities in both lenses. The patient was a woman, 43 years old, who had V. 5/6. The corneal pigmentation was almost symmetrical, a broad streak of very fine color particles, downward and to the nasal side. The streak occupied about half of the cornea. The upper part, left free, was larger than the lower part. The streak was broadest (2 to 2.5 mm.) a little below the corneal center. The pigmentation was peripherally the least dense. The pigment showed clearly against the posterior wall of the cornea.

The writer considers the lens opacities to be a light form of congenital zonular cataract, and the pigment deposits to be congenital melanosis of the cornea.

Pigmentation of the sclera. These deposits are usually congenital. See p. 2947, Vol. IV of this *Encyclopedia.*

E. J. Smyth (*Trans. Oph. Soc. U. K.*, p. 142, 1914) exhibited a female, 20 years of age, who complained that for a period of about twelve years the white of one eye had gradually become discolored. The sclera, particularly in its lower-inner part, was occupied by patchy pigmentation. The upper and inner quadrant, on the other hand, remained free from the change and the iris was more pigmented than usual.

Pigment of the iris. See p. 6638, Vol. IX of this *Encyclopedia.*

Pigmentation of the lens. This rare anomaly is to be distinguished from deposits on the anterior surface due to some form of iritis, and are generally congenital. Some authorities claim, however, that the lenticular pigment is always derived directly from the uveal pigment or, as in Mittendorf's cataract, from the hyaloid artery.

M. S. Mayou (*Ophthalmoscope*, p. 532, Oct., 1916) reports the following case: A. P., male, aged 29 years, instrument-maker. The patient came with a history of failing vision in his right eye for six months. On various occasions he has had several foreign bodies in the eye, as he works with the lathe. These have been removed.

On examination, the vision was less than 6/60, and when the pupil was dilated, there were opacities in the anterior capsule of the lens and also in the deeper portions of the lens, with several red spots almost the color of rust. The case was X-rayed on two occasions but no foreign bodies could be found in the eye.

The appearance is suggestive that a tiny piece of steel may have at some time entered the lens, although no entrance wound can be found. The red spots are probably oxide of iron.

Pigment on the optic disc. See p. 2948, Vol. IV of this *Encyclopedia.* Here attention may be drawn to the case reported by Pálich-Szánto of a soldier (aged 26) with normal vision who showed in his left eye a pigmentation of the nasal half of the optic disc. The pigment con-

sisted of fine granules that lay chiefly on the surface, but were also noticeable in the deeper portions.

After discussing the different explanations of pigmentation of the disc, the writer considers the following three as the most probable:

1. Embryonic scattering of germs producing an isolated group of pigmented cells at places where they do not occur normally.

2. From embryologic investigations Pick found that in the human embryo at the seventh week, or perhaps earlier, marked tracts of pigment pass from the pigment layer of the eye into the optic stalk. Hence it may be possible that these pigment tracts occasionally persist and cause pigmentation of the disc.

3. According to Berger, the inner strata of the lamina cribrosa originate from the choroid, and their peripheral portions always contain pigment cells. Berger ascribes the pigmentation of the disc to the hypertrophy of these cells.

Pigmented retina and choroid. Disturbances and heaping up of the retino-choroidal pigment (which even in health varies much in individuals) are seen in numerous pathological states—ante- and post-partum. The most common alteration is that accompanying the so-called *retinitis pigmentosa.*

Speculations as to the origin and cause of the pigmentation in this disease will be found in an article by Suganuma (*Klin. Monatsbl. f. Augenh.*, p. 175, 1912) who reports a typical instance of retinitis pigmentosa in a man aged 67, with optic atrophy, narrowed vessels and night blindness. The eye was lost from hypopyon ulcer. Pathological examination showed complete loss of the rods and cones; some remains of the outer nuclear layer were present near the nerve entrance and at the fovea; the inner nuclear and ganglion cell layers were partially degenerated; the nerve fiber layer and the optic nerve were atrophic; the neuroglia was proliferated. The retinal vessels were sclerosed and in places obliterated. At the posterior pole and anteriorly the pigment epithelium was fairly regular; in the equator it was absent in some areas, proliferated in others. The choroid showed only slight atrophy, which the author regarded as senile. The chorio-capillaris was normal in nearly the whole of its extent; in a few small areas only it was imperfect or absent. There was no sclerosis of the choroidal vessels.

This report seems to confirm the observations of Stock and Ginsberg, that the chorio-capillaris and choroidal vessels are much less affected in retinitis pigmentosa than theoretical considerations would lead one to suppose. Both these authors believe that the disease must be primarily retinal, and Ginsberg assumes an abiotrophy of the rods and cones, in consequence of which they fail to survive for their normal

life-period. Against this view Suganuma urges that it does not take account of the disease of the retinal vessels. He adopts the hypothesis that the retinal vessels may be the primary seat of disease, an explanation which seems quite indefensible when one considers that the outer layers of the retina are affected; or that the vascular disease and the disease of the rods and cones are simultaneous and due to the same cause. The pigment invasion, he believes, is caused by the breaking up of the rods and cones, which may act in the first place by giving rise to stimulating degenerative products, and in the second by altering the organic relations of the parts, relieving the epithelium, as it were, from control on its inner surface, and providing space to be filled by its proliferation. In the retina also the degeneration of the nervous elements will cause a loosening of the tissues and so prepare the way for pigment invasion.

There are some objections to this hypothesis of a primary retinal disease, chief among which perhaps are the facts that no other purely retinal disease or degeneration is known to cause pigment proliferation, and that many of the features of retinitis pigmentosa (pigment proliferation, narrowing of vessels, yellowish atrophy of the nerve) are imitated in undoubted disease of the choroid. At the same time a priori reasoning must give place to actual observation, and in deciding the part played by the choroid cases of advanced disease such as the present, are almost more valuable than cases still in an early stage. It should be remembered also that none of the ordinary degenerations of the retina quite fulfil the conditions hypothecated for retinitis pigmentosa—a primary breaking down of the rods and cones; the data therefore are lacking from which the results of such a degeneration could be predicated. (George Coats in *Oph. Review,* May, 1912.)

Pigment ball. That discrete, pathological collections of pigment may form between the retina and the choroid is well known. For example, Alt and Hardy (*Am. Jour. of Ophthalmology,* June, 1915) examined the eyeball of a child which had received a penetrating injury and had in due course become phthisical. The examination threw no particular light on the finding of a large ball of dense pigment, so dense that individual cells could not be made out, behind the detached retina and a little posterior to the *pars non plicata* of the ciliary body. The ball measured one millimeter in diameter in the hardened specimen. It was surrounded by an envelope of fibrous connective tissue. At one point the envelope was broken and the pigment cells were spread over the edges to some extent, giving the appearance as if the pigment ball had broken off from the tissue from which it sprang. There is hardly any doubt, the authors say, that this was the pigmented epithelial cell layer,

Of the influences at work to produce such a large ball of pigment the authors do not offer any opinion.

Pigmented cataract. Pigmentous cataract. A false cataract, usually produced by a violent concussion or blow on the eye, or by an iritis, which has detached the pigment from the posterior surface of the iris, whence results a sort of arborescent appearance.

Pigment epithelium. Of the retina. See p. 5961, Vol. VIII of this *Encyclopedia.*

Pigmentirter Staar. (G.) Pigmented cataract.

Pigmentous (or pigmented) cataract. An obsolete expression intended to indicate "a false cataract usually produced by a violent concussion or blow on the eye, which has detached the pigment from the posterior surface of the iris, whence results a sort of arborescent appearance."

Pigments. Stains. Dyes. For practical purposes the substances generally known as pigments may be considered either as paints, varnishes, stains, or dyes. The last two are identical in many instances, the substances upon which their application is made, and the method of applying them, determining whether they shall be called "stains" or "dyes." Thus we speak of "staining" a piece of wood, and of "dyeing" a cotton or wool fabric, although the pigment used in each instance may be the same.

Generally speaking, dyes, stains, and varnishes are transparent or translucent substances in solution, or chemical combination, with a liquid; while paints are opaque, insoluble substances, held in suspension in some medium. Thus a stain or dye enters into intimate combination with the wood or the fabric to which it is applied. Being transparent it does not conceal the grain of the wood or the fibers of the cloth that it colors, and does not increase its thickness to any appreciable depth. A paint, on the other hand, simply covers and conceals the underlying structure by an appreciable layer without becoming an integral part of it. This is shown in the familiar example of paint peeling off wood, leaving the original surface exposed.

A varnish is essentially a transparent paint, rather than a stain. Color effects may be produced very much the same as in the case of stains by incorporating a transparent pigment in the varnish; but it is possible for a varnish to peel off from an underlying surface just as in the case of a paint.

Pigmentschicht. (G.) Pigment layer.

Pigment spots, Fuchs'. Ronnd deposits of pigment about the macular region in high degrees of myopia, associated with surrounding atrophic areas or not, have been noticed by many observers, but first by Förster in 1862. They are hyperplastic pigment areas and are always accom-

panied by low vision. Because that authority has recently described and depicted them they are generally known as Fuchs' pigment spots.

Pigmentum nigrum. Of the embryonic eye, the proximal lamella of the secondary optic vesicle.

Pikkolo ophthalmoscope. F. Baum (*Klin. Monatsbl. f. Augenheilk.*, May, 1913) has described an electric ophthalmoscope in which the rays of light are deflected by a prism rather than reflected by a mirror. See **Baum's electrical ophthalmoscope.**

Pili palpebrarum. The cyelashes; also the free margins of the eyelids.

Pilocarpine. This important alkaloid exists, with several others, chiefly in the dried leaflets of *pilocarpus microphyllus,* the jaborandi shrub of Brazil, in which it is found to the extent of one per cent. The pure alkaloid is a colorless, syrupy fluid, soluble in water. It is not used in ocular therapy, although the official tincture, solid and fluid extracts of jaborandi occasionally are. The best known salts, usually white crystals soluble in water, are employed in about the same dose as topical agents, viz., ½ to 10 per cent. These are the borate, hydrobromide, hydrochloride, nitrate, salicylate, sulphate, tannate and valerianate.

Pilocarpine is incompatible with silver nitrate, corrosive sublimate, tannin, the permanganates, alkalies and the iodides.

The hydrochloride is extensively used in from a half to four per cent. solutions, as a miotic. It is, clinically, a somewhat milder remedy than eserine (q. v.). It is employed chiefly in glaucoma, corneal ulcer and for all purposes where a weak pupil-contractor is desired. Both the jaborandi preparations and all the pilocarpine salts are poisons and care must be observed in exhibiting them hypodermically or for subconjunctival use. The value of pilocarpine as a sialagogue and diaphoretic in the general treatment of intraocular diseases by means of sweat-baths or the iodides has been admitted. In this connection it should be given by hypodermic injection in doses of $\frac{1}{12}$ to ¼ grain.

The following formula makes a good, average prescription that does not easily decompose and that may be used three times daily in cases where a weak miotic is needed or where eserine is not well borne: ℞ Pilocarpin. hydrochlor. gr. iii (gm. 0.2); Sodii chlor. gr. ⅙ (gm. 0.01); Sol. hydrarg. bichlor. $\frac{1}{5000}$ fl. ʒiiss (cc. 10.0).

Lilienfeld has shown that impure pilocarpin may contain jaborin, an isomeric form of pilocarpin which is really a mydriatic. As the presence of this drug neutralizes to some extent the clinical value of any pilocarpin preparation into which it enters, only those drugs made by the best pharmacists should be employed.

Pilocarpin-morphin. A mixture of a two per cent. solution of pilocarpin, with one-tenth of one per cent. morphin, recommended by Eversbusch to relieve the symptoms of acute glaucoma.

Pilots, Examination of the eyes of. See **Eyes of soldiers, sailors, railway and other employees, Examination of the.**

Piltz, Pupillary reaction of. Gifford's reflex. See p. 5384, Vol. VII of this *Encyclopedia.*

Pilulæ opticæ. A purgative preparation containing 60 grammes of extract of aloes, 11 of prepared amber, 7, each, of valerian root and euphrasia root, and 4, each, of fennel seeds, sesels seeds, aloes wood, yellow saunders, cubebs, lesser cardamom, agaric, sassafras bark and alhandal troches.

Pilz, Joseph. A celebrated Bohemian ophthalmologist, author of the justly esteemed *"Lehrbuch der Augenheilkunde."* Born in Bohemia in 1818, he received his medical degree in 1843 at Prague, was from 1845-'47 assistant in ophthalmology, in 1849 privatdocent, in 1854 extraordinarius, and in 1857, national ophthalmologist for the Kingdom of Bohemia. He died suddenly of apoplexy, Aug. 6, 1866, at the early age of 48.

Pilz's ophthalmic writings are as follows:

1. Ueber die Gefässentwicklung in der Hornhaut. (*Prager Vierteljahrschr.*, XX.)
2. Ueber Hornhautexsudate. (*Ibid.*, XXIV.)
3. Die Pathologie des Krystallinsensystems. (*Ibid.*, XXV.)
4. Ueber Bindehautentzündungen und Trachom. (*Ibid.*, XXVIII.)
5. Ueber Hypertrophie und Atrophie der Sclerotica, mit Vorzügl. Rücksicht auf Staphylombildung. (*Ibid.*, XXXIV.)
6. Ueber Entzündung der Sclerotica. (*Ibid.*, XXXVI.)
7. Therapie des Trachoms. (*Ibid.*, XLII.)
8. Entzündung der Regenbogenhaut. (*Ibid.*, LXXIII.)
9. Lehrbuch der Augenheilkunde. (Prague, 1859.)
10. Compendium der Operativen Augenheilkunde. (Prague, 1860.)
11. Diagnostisch-therapeut. Compendium der Augenkrankheiten. (Prague, 1862.)—(T. H. S.)

Pilzgift. (G.) Mushroom poison.

Pimelopterygium. A fatty outgrowth upon the conjunctiva.

Pimpernel, or anagallis. The juice of this plant, mixed with honey, is recommended by Dioscorides for weakness of the sight and affections of the cornea. Pliny (xxv, 92, 99) declares that the juice of anagallis enlarges the pupils, and should therefore be employed prior to the operation of paracentesis. The modern anagallis, it is hardly necessary to add, possesses no such property. Either Pliny (who was not

much of a physician, and often a prevaricator) was giving free reign to his imagination in the passage above referred to, or else the modern anagallis and the ancient plant bearing the same name, are not identical.—(T. H. S.)

Pin. Same as **Caligo.** See, also, **Web.**

Pin and web. An obsolete term, defined as follows in Quincy's "*Lexikon Physio-Medicum*" (1757) under "Albuginea Oculi": "A white Speck in the horny Tunicle of the Eye that obstructs the Sight." Under "Pin and Web," the term is somewhat differently defined in the same work: "an horny Induration of the Membranes of the Eye, not greatly unlike a Cataract."—(T. H. S.)

Pince à érignes. (F.) Hook-forceps.

Pince à fixe. (F.) Fixation forceps.

Pince à griffes dents de souris. (F.) Squirrel-toothed forceps.

Pince à iris. (F.) Iris forceps.

Pince à nettoyer les plaies. (F.) Dressing forceps.

Pince à plaque pour paupières. (F.) Flat lid forceps.

Pince à pression continué. (F.) Pressure forceps.

Pinces à tourmaline. (F.) Tourmaline tongs.

Pince capsulaire à triple articulation. (F.) Three-toothed capsule forceps.

Pince-ciseaux. Scissors-forceps.

Pince-ciseaux of de Wecker. See p. 136, Vol. I of this *Encyclopedia.*

Pince courbe. (F.) Forceps of the iridectomy type.

Pince-cystitome. A name given by de Wecker to an instrument like a curved iris forceps, to be used as a cystotome, each branch terminating in a triangular cutting blade. By it a square flap of the lens-capsule may be removed. See **Cataract, Senile.**

Pince droite. (F.) Straight forceps.

Pince-nez. (F.) Eyeglasses kept in position by a spring. See **Eyeglasses.**

Pince pour enrouler la paupière. (F.) Roller forceps.

Pince pour retirer les fils. (F.) Suture forceps.

Pincettenscheeren. (G.) Scissors-forceps.

Pincushion distortion. Distortion caused by a convex lens.

Pineal gland. A rounded body about the size of a pea, of a slight yellowish color, situated upon the anterior pair of corpora quadrigemina, and connected with the optic thalami by two strands of nerve fibers termed its peduncles. It contains small cavities in its interior. It has been recently discovered to be a developmental remnant of a third eye, the elements of which can still be distinctly traced in some of the lower vertebrata.

Its nervous nature is doubtful, and its function in man obscure or absent, but it is constant among vertebrates, and in several, especially lizards, it is connected with a more or less rudimentary eye in the middle of the top of the head.

See **Insects, Eyes of**; **Crustaceans, Eyes of**; **Comparative ophthalmology.**

Pineo-pituitary. Pertaining both to the pineal gland and to the hypophysis cerebri.

Pinguecula. Pinguicula. This growth is a small, yellowish-white (probably colloid) elevation in the ocular conjunctiva, usually situated near the corneal limbus towards the outer or inner canthus. It is composed of thickened connective tissue and is not a fatty deposit, as its appearance and name might suggest. It is an innocent growth, except when it is a forerunner of pterygium, and rarely requires removal.

Pinhole photography. Photography by means of a small hole, without the use of a lens. See **Camera obscura.**

Pink-eye. Contagious conjunctivitis. An acute contagious catarrhal conjunctivitis characterized by a pink or red appearance of the eyeball. See p. 3089, Vol. IV of this *Encyclopedia.* The bacterial cause of this disease is commonly supposed to be due to the Koch-Weeks bacillus (q. v.) but many epidemics have shown little evidence of that morbific agency; other organisms, such as streptococci, bacilli xeroses and their combinations with the pneumococcus being chiefly noticeable.

Pinto, da Gama. C. A. Claudio Julio Raymundo da Gama Pinto was born at Goa, East Indies, in 1853. He studied at Porto, Lisbon, Paris, Vienna and Heidelberg. For a time he served on the Health commission in Portuguese India. Later he was Professor of Medicine in Goa, but removing to Heidelberg and devoting himself to ophthalmology exclusively, he became in 1880 Assistant to the Eye-Clinic in Heidelberg University. In 1885 he was made privatdocent. He wrote "*Untersuchungen über Intraoculare Tumoren. Netzhautgliome*" (Wiesbaden, 1886).—(T. H. S.)

Pinzetta a fissazione. (It.) Fixation forceps.

Pioscope. A form of lactoscope.

Pip. A contagious disease of poultry affecting the eye, nostrils and tongue.

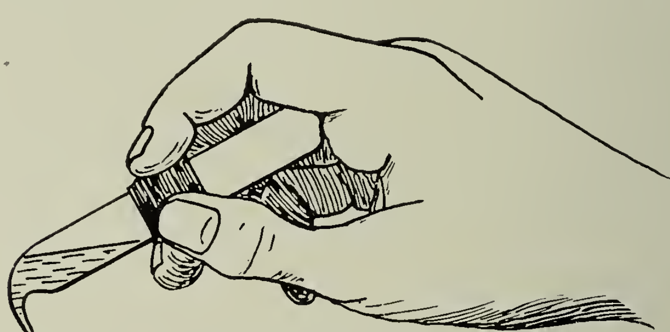
Piper citrifolium. One of the plants used in Brazil under the name jaborandi.

Pipette. A glass tube or narrow vessel, with or without expanded portions, graduated or not, open at both ends, generally drawn out to a moderately small size at one end, used in chemical manipula-

tions for conveying definite quantities of liquids. See **Dropper, Medicine.**

Pipino, W. C. A well known ophthalmologist and otologist of Des Moines, Iowa. He was born in Baltimore, Md., in 1851, at the age of 35 removed to Des Moines, where he acquired a wide reputation, and where he died in 1896 from injuries received when thrown from a horse.—(T. H. S.)

Pirquet's (Von) test. Cutaneous tuberculin reaction. In his work on vaccination against smallpox, v. Pirquet observed that frequently a decided hyperemia developed at the site of a revaccination in cases previously successfully vaccinated. This observation, coupled with the results of his studies on the phenomena of serum hypersuscepti-



Ballantyne's Pipette with the Fore-finger Placed on the Rubber Band over the Opening, to Control the Drops.

bility or "serum sickness," suggested the possibility of a bacterial hypersusceptibility in the subjects of bacterial infection, which might be employed in diagnosis. In 1907 he published the results of his studies on the cutaneous tuberculin reaction.

v. Pirquet applied a small drop of tuberculin to the skin, and through the drop, scarified a small area, avoiding any bleeding. After 24 hours an area of hyperemia appeared, in the center of which a small papule developed, which slowly subsided after a few days. Control scarifications produced no reaction. He later modified the method by making a series of scarifications using several dilutions of the tuberculin. His first paper summarized 360 observations mainly on children. In 88 per cent. of tuberculous cases he obtained a positive reaction. In the advanced cases, and in miliary tuberculosis the reaction did not appear. In 100 cases in which post mortems were obtained, 47 were found tuberculous, and of these 30 had given the reaction; the other 17 were

either advanced or miliary cases. Of the 53 non-tuberculous cases, only one had given a positive reaction.

The work of v. Pirquet was taken up by a number of other observers, and his results were in the main confirmed. It appeared, however, that in the cases classed as "suspected" and "non-tuberculous," the reaction was positive in a larger proportion of cases than the clinical manifestations warranted, i. e., the test reacted to healed or latent tubercle, and hence was too delicate to be of practical value. By limiting more rigorously the definition of a "positive reaction," the ultra delicacy of the test has been largely done away with, and the cutaneous reaction of v. Pirquet has become a valuable aid in diagnosis.

Pisselæon. Twice-boiled pitch. An esteemed ophthalmic remedy in the days of Dioscorides. See **Pitch.**

Pit, Tear. Lachrymal sinus.

Pitcairn, Archibald. Born at Edinburgh, Scotland, in 1652, he was bred for both the bar and the pulpit, but later studied medicine at Montpellier, Paris and Edinburgh. At the last named institution he received his medical degree. He also began to practice in Edinburgh, but was soon (in 1692) called to Leyden, Holland, to the chair of medical practice. On entering this position he presented an "Oratio qua Ostenditur, Medicinam ab Omni Philosophorum Secta esse Liberam," in the course of which he presented his "Theoria Morborum Oculi." In this he pointed out certain matters of much historical importance for the development of a correct etiology of *mouches volantes*. It had been supposed that these appearances were owing, in greater part, to opacities either on or in the cornea, and also, to some extent, to obstructing bodies in the pupil or the lens. Pitcairn showed that the distance from the cornea (*a fortiori* from the pupil or the lens) to the retina is far too small to permit of images of matters so located being cast upon the retina. Deschales (q. v.) had already shown (in 1674) by a simple, but excellent, diagram that *mouches volantes* must of necessity be seated in the vitreous, and not very far in front of the retina. Nevertheless Pitcairn (for the very first time in history, so far as I have been able to ascertain) performed an experiment whereby he showed conclusively that corneal, pupillary and lenticular opacities can only diminish the quantity of light permitted to reach the retina, that, in other words, they have no power to cast upon the retina either an image or a shadow of themselves. This he did by placing in water a glass sphere, and showing that parallel rays which fell upon it were brought to a focus only at $3\frac{1}{2}$ diameters *behind its posterior* surface. He also pointed out the folly of attempting to

remove such disturbances of vision by treatment directed to the cornea.

Pitcairn wrote a number of other books, which, however, possess no special interest for ophthalmologists.

He seems to have been an invalid for the greater portion of his life. An accurate scholar, he was also an eloquent speaker and was naturally very popular with his students. He was a staunch royalist, throughout the troublous times in which he lived. He died in 1713.—(T. H. S.)

Pitch. *Pix spissa* and *pix liquida.* In ancient Greco-Roman times, the soot of pitch was used on the borders of the eyelids as a cosmetic, and was also employed in the conjunctival sac as a valued remedy in corneal affections. The twice-boiled pitch was known as pisselæon.—(T. H. S.)

Pits, Corneal. See **Cornea, Pitting of the.**

Pituitary disease, Ocular relations of. The functions and interrelations of the ductless glands have been the subject of much research in the past decade, with the result that the hitherto obscure organ known as the pituitary body has assumed a large place as one of the producers of internal secretions and an undoubted disturber of both anatomic and physiologic integrity throughout the organism. The location of this structure, adjacent to the optic chiasm and cavernous sinuses, is such that its enlargement is quickly revealed by pressure affecting the nerve and blood supply of the eyes; therefore the ophthalmic relations of pituitary disease have received increasing attention in recent years.

As Uhthoff has said, temporal hemianopsia and amaurosis were the striking symptoms on which the diagnosis of pituitary tumors depended in the preophthalmoscopic days and the recognition of a more extended symptomatology necessarily awaited the era of more exact diagnostic methods. At the present time, however, we must regard pituitary disease as not infrequent and bear in mind this possibility when confronted by obscure cases of exophthalmos, ocular muscle palsies, optic nerve disease, various visual field limitations and evidence of general intracranial hypertension.

The student of this subject will find the most complete and illuminating presentation in the work of Harvey Cushing (*The Pituitary Body and Its Disorders,* 1912) which summarizes the researches at the Johns Hopkins laboratories and elsewhere, with a tentative classification of pituitary disorders and a very full bibliography which need not be repeated here. The reader is also referred to the work of Wilhelm Falta which treats of the entire series of ductless glands and is of later date (*Die Erkrankungen der Blutdrüsen,* Wien, 1913). The

researches of Reginald Allen also form an important contribution to our knowledge of this subject.

The hypophysis cerebri, or pituitary body (so-called from the erroneous supposition that it secretes ''pituita'' or mucus into the nose), is a complex structure made up of tissues of separate origin. It is reddish-gray, of oval shape, with the widest diameter transverse. In man it weighs somewhat more than ½ gram. Depending from the floor of the third ventricle to which it is joined by the infundibulum, it rests in the sella turcica of the body of the sphenoid bone closely embraced by dura mater which penetrates the foramen sellæ turcicæ above along with the infundibular stalk. The hypophysis lies below and posterior to the optic chiasm and between the two cavernous sinuses. Each cavernous sinus lies between layers of dura mater at the side of the body of the sphenoid, extending from the sphenoidal fissure in front where the ophthalmic veins empty to the apex of the petrous bone behind where it ends in the petrosal sinus. The cavernous sinuses are connected across the midline of the sphenoid in front and behind, and sometimes beneath the pituitary body, by vessels which collectively are called the sinus circulosus (intercavernous sinus). The third, fourth, and ophthalmic division of the fifth cranial nerves lie along the outer wall of each cavernous sinus, and the sixth cranial nerve and the internal carotid artery, which is surrounded by filaments of the sympathetic nerve, lie along the inner wall. These anatomic relationships insure an extensive symptomatology even with slight enlargement of the hypophysis. (See **Cavernous sinus, Ocular relations of,** Vol. III, page 1794, of this *Encyclopedia.*)

The hypophysial vesicle is formed by an evagination of the mucous membrane of the buccal cavity (ectoderm) joining with a projection from the floor of the third ventricle. The former becomes the anterior lobe (pars anterior), the latter the posterior lobe (pars posterior or nervosa). The epithelium of this projection is differentiated from the anterior epithelium to form the pars intermedia, the cavity of the original vesicle remaining as a cleft separating the pars anterior from the pars intermedia.

The anterior lobe, larger and partly embracing the posterior lobe in its concave border, consists of loose connective tissue with many blood vessels and nerves and of solid branched epithelial cords varying in calibre and frequently anastomosing. Near its border towards the posterior lobe a few columns are hollow and sometimes contain colloid masses. The epithelial character of this lobe is emphasized. Its function is based upon the presence of two kinds of cell, the chromophile (eosinophile) which predominates when this lobe is hyperfunctioning,

and the chromophobe which predominates when this lobe is hypofunctioning. Non-granular cells have also been differentiated from the so-called ''Schwangerschaftszellen'' form in the hyperpituitarism of pregnancy. The blood supply of the anterior lobe is derived from the arteriæ receptaculi, branches of the internal carotids, and finds exit into the sinus circulosus. The secretion of the anterior lobe is probably discharged into the neighboring thin-walled venous sinuses.

The pars intermedia is separated from the pars anterior by a narrow cleft. This intermediate portion constitutes an epithelial investment for the pars posterior, having a tubular arrangement of cells which invade the nervous tissue extending, in man, nearly to the infundibular canal. These cells secrete a colloid substance comparable to that found in the thyroid gland.

The posterior lobe consists of a loosely interlacing nerve-fibre network, ependymal and neuroglial tissue, many blood vessels, and cells closely resembling bipolar ganglion cells. The blood supply is derived from the meningeal branches of the internal carotids and finds exit into the sinus circulosus. The secretion of this lobe is discharged into the cerebro-spinal fluid.

Observations on man and animal experimentation have opened up a considerable store of information in regard to pituitary function and suggest many further questions for solution. Each lobe, by excessive or diminished functioning, may produce a symptom complex; one lobe may hyperfunction with pressure atrophy of the other lobe, giving a most complicated picture which present-day knowledge cannot clarify. The question of relative activities among the several members of the ductless gland series, the ''pluriglandular syndrome''; the normal hypertrophy of the pituitary body at puberty and during pregnancy: changes characteristic of the climaterium; the therapeutic uses of pituitary extract in menstrual disorders and labor and in obesity; the possibility of brain pressure, not hypophysial in origin, impairing hypophysial function or preventing the escape of normally elaborated hypophysial secretion; these and many other questions not strictly germane to the ophthalmological aspect of the subject indicate the extensive range of interests developed from a study of the hypophysis.

Experimental knowledge of the several tissues contained in the pituitary body justifies the following statements. The anterior lobe is essential to life, its total extirpation causing death from cachexia. Injection of anterior lobe extract causes some pressor effect upon the circulation (possibly due to traces of the pars intermedia which

is known to possess definite pressor qualities). Undersecretion causes lowering of body temperature.

Acute overactivity of the posterior lobe results in a rise of blood pressure with slowing and strengthening of the heart beat, diuresis (due to stimulation of the renal epithelium), uterine contraction, dilatation of the pupils, increased carbohydrate assimilation (lowered tolerance), and a galactagogue action. Chronic oversecretion produces emaciation. Undersecretion causes increased carbohydrate tolerance. Cushing believes that "normal posterior lobe activity is essential to effective carbohydrate metabolism." While the posterior lobe is concerned especially with processes of metabolism, the anterior lobe is concerned with skeletal growth.

The symptoms of glandular hypertrophy have not been duplicated by feeding with pituitary extract; but the effects of undersecretion have been observed after partial hypophysectomy. They embrace adiposity; nutritional changes in the skin and its appendages; disturbance of carbohydrate metabolism, body temperature, growth and renal secretion, with sexual inactivity and atrophy. The adiposity is generalized; the skin becomes dense, dry, and less movable; the temperature is subnormal; mental dullness arises with irritability; and there is diminished sensibility to pain.

Thus it is possible to make a classification of pituitary disorders based upon excessive and diminished secretion. A large group of cases does not fall into either of these divisions, for they exhibit the effects neither of a frankly overactive nor underactive gland. To these cases the term "dyspituitarism" applies. They represent perverted function, partly overactivity, partly underactivity, at times secondary effects of pressure upon the hypophysis from adjacent structures. Hyperpituitarism is typified by giantism and acromegaly. When glandular overactivity occurs in childhood general overgrowth of the bony framework results. When oversecretion is delayed until epiphysial union has taken place (after puberty) the overgrowth is limited to the acral parts and the condition of acromegaly results. Excessive multiplication of the eosinophile cells of the pars anterior is characteristic of hyperpituitarism. Hypopituitarism is best illustrated by the Fröhlich syndrome or "dystrophia adiposo-genitalis" of Bartels, a condition of generalized adiposity with delayed development of the genital organs, scant pubic and axillary hair, dry skin and polyuria, secondry sexual characteristics failing to develop. When the disease begins in adult life there are retrogressive changes (amenorrhea, testicular atrophy, loss of sexual power and desire) and

a loss of the secondary sexual characteristics with the assumption of the feminine contour of body by males. A chromophobe struma is the characteristic lesion in this group representing the hypofunctioning gland.

These groupings will be illustrated by the following cases. Hyperpituitarism will be presented in the form of (1) infantile giant growth, of (2) a "professional giant," of a (3) "normal giant" who became acromegalic in adult life, and (4) a woman of normal size who developed acromegaly in adult life.

(1) Giantism may reveal itself in infancy, as in Crile's case recorded by Cushing (*The Pituitary Body and Its Disorders,* 1912, page 29). "A female infant, aged 3, notably backward in mental and physical attributes, began abruptly at two and a half years of age to grow with extreme rapidity. She became drowsy and excessively fat. The obesity was ultimately associated with a general tenderness (adiposis dolorosa) and with polydipsia and polyphagia. Five weeks before coming under observation an area of pressure atrophy from a subjacent tumor appeared over the left frontal region.

"Examination. The child was overgrown and exceedingly adipose—twice as large as the usual child of three. Her waist measured 57 cm., her hips 60 cm. Her height was 90 cm. The hair was luxuriant and the skin coarse, giving her a peculiar gross appearance. The thyroid was not palpable. The temperature was slightly elevated. Thyroid extract was tentatively given, without improvement. Operative interference was unthinkable. She died three weeks later.

"A postmortem examination (limited to the head) disclosed a large 'mixed-cell sarcoma.' The pituitary fossa was 'subjected to sufficient direct pressure to flatten it out.' " This was interpreted as a case of primary hyperpituitarism with rapid change to hypopituitarism with the excessive tumor formation.

(2) The case reported by Bassoe (*Jour. Nervous and Mental Dis.,* 1903, XXX, 513, 595) of the celebrated giant, Lewis Wilkins, may be described as an example of what is now quite definitely regarded as a product of excessive pituitary functioning in childhood. Wilkins was a professional giant exhibiting himself in America and Europe, and receiving mention from time to time in medical literature. Dana, of New York, reported his case in 1893, Lamberg presented him before the Vienna Medical Society in 1896, and numerous writers quote these observers' comments upon giantism as seen in the person of Wilkins.

The following description is abbreviated from Bassoe's report upon the case as studied in the Presbyterian Hospital in Chicago for a

period of twelve days before death in 1902 and followed to autopsy. Wilkins was then 28 years old.

Physical examination shows a man 8 feet 2 inches in height, 56 inches around the chest and well proportioned. A growth on the left side of the head extends from the median line outward and backward as far as the external auditory meatus and downward over the face to the alveolar process of the superior maxilla. The mass is firm except in a small area above the external auditory meatus where it fluctuates. The left eye is closed, the upper lid being thickened and drooping; the pupils are inactive. The left side of the face and tongue is anesthetic. A bilateral choked disc is found.

Anatomic diagnosis was "necrotic and ulcerative colitis and ileitis; cirrhosis of liver; chronic catarrhal gastritis; epitheliosis of esophagus; hemorrhagic bronchopneumonia; enlargement of thyroid; sarcoma in region of hypophysis; extension of tumor to subcutaneous tissues; diffuse hyperostosis of frontal, left parietal, left temporal and left superior maxillary bones; calcification of left pleura and spinal arachnoid; compression of brain; general giantism." The following observations are important from the standpoint of pituitary participation in giantism: "The base of the skull is greatly deformed. On the left side the anterior fossa is obliterated by the thickened frontal lobe, and the middle fossa also is almost filled in with bone. The sella turcica is wide, its floor partly eroded. In this region is a large tumor mass which has grown into the pharynx, orbits and ethmoidal sinuses, and has destroyed the roof of the nose; the roof of the left orbit has been much more extensively invaded than the right. In the median line of the surface of the tumor exposed at the base of the skull after removing the brain is a projecting pedicle, darker than the tumor mass. This is found to be the infundibulum." "The left optic nerve is narrower than the right. The other cranial nerves appear symmetrical." The tumor is designated an osteoplastic sarcoma with edema and mucoid degeneration. The hypophysis was not invaded by the tumor mass, but was flattened by pressure; some of the blood vessels of the hypophysis were engorged and some hemorrhages were found. The testicles showed some areas of round-celled infiltration, some of increased fibrous tissue and hyaline changes in the seminiferous tubules.

This report antedated the present era of interest in hypophysial disorders and contrasts with some of the studies recorded further on. Had it occurred ten years later, it might have revealed some of the metabolic disturbances now associated with pituitary perversions. It is interesting to note that Bassoe refers to the bold suggestions made by some writers as to the oneness of giantism and acromegaly, both representing hyperpituitarism beginning at different times of life—suggestions since proven to be correct. This case also exhibits the possible confusion of bony enlargement of the face with acromegaly, one writer having descrbed Wilkins as an acromegalic. That both excessive growth in childhood and subsequent acromegalic changes can occur is shown by Cushing's case of a "normal giant" as Sternberg has called overgrown individuals who are well proportioned.

(3) This history is abbreviated from Cushing's book (*The Pituitary Body and Its Disorders*, page 30 ff.) December 8, 1910. M. Van W., a farmer, single, aged 35; complaint: acromegaly with threatened loss of vision. Patient weighed 10 pounds at birth; usual diseases of childhood; at 13 years of age began to grow rapidly and at 19 was about 6 feet 4 inches tall, weighed 200 pounds and was exceptionally strong;

intelligent and studious, and of good habits except for an uncontrolled libido sexualis. "At 23 (1898) he had a severe illness accompanied by marked polyuria, and followed by a persistent furunculosis (diabetic?). He was said to be threatened with consumption. At 25 there seem to have been no traces of acromegaly. He and his father are positive that a second period of growth began eight years ago (æt. 27), antecedent to the present malady."

Violent bursting frontal headache in 1903, with pain in the extremities; quantities of slimy mucus, sometimes bloody, were discharged from the nostrils at these times. Relief would follow these attacks for several days. At this time he was told that he had acromegaly. Failure of vision began in 1905 with diplopia and possibly hemianopsia. In 1907 his features were noticeably changing and he was growing larger and at the same time physically weaker. He now had polyuria but not glycosuria so far as is known. Weakness, drowsiness, tiring quickly, entire loss of sexual desire and power now occurred. Reading vision was lost one year ago (1909). The left eye is now blind and the right nearly so. Appetite is excessive; he is very constipated; his disposition is not especially changed. Height 6 feet, 6 inches; weight 269 pounds; "he is a veritable Gargantua"; blood pressure exceedingly low (75 to 100 mm. Hg.); urine and blood negative.

The X-ray shows the sella greatly enlarged (3.5 cm. antero-posteriorly, 2.8 cm. deep); anterior and posterior clinoid processes are separated 2.5 cm. and the "thin dorsum sellæ is tilted back indicating an extension of the glandular struma into the cranial cavity." Eyes large, prominent, widely separated, with divergent squint; bilateral primary optic atrophy "and only two small remaining patches of vision to be plotted for the right eye with 4 cm. discs—a superior hemianopsia." There is a protrusion in the pharyngeal vault resembling adenoid tissue. Paroxysmal headaches have subsided but he is dull and falls to sleep during conversation; there is no evidence of choked disc past or present.

In spite of growing round shouldered he is taller than formerly (6 feet, 6 inches); "growing pains" have been felt in the extremities; hands and feet are huge; frontal bones are prominent, lips and tongue very large, mandible wide and protruding. X-ray of the hands shows characteristic tufts and thickenings. Subcutaneous tissues of the soles of the feet are greatly thickened. The skin is moist and smooth; much boggy edema, especially of the lower extremities and eyelids. Body hair is scant and of feminine distribution. Hair of the scalp is abundant and coarse. Subcutaneous fat is excessive and one distinct lipoma is seen under the left scapula.

Carbohydrate tolerance is increased; temperature is subnormal, blood pressure is low; there has been polyuria. The testicles, adrenals and thyroid show evidence of diminished function. Operation (sellar decompression by sublabial approach) reveals a tumor mass under tension, chromophobe cells predominating with no eosinophiles. There was some improvement in vision and a return of color perception. Six months later the patient was less drowsy and nervous and had some further improvement of vision; weight was increased; temperature was normal and he felt stronger.

This is a case of giantism within the limits of the "normal"; that is, an individual of general good proportions and with physical strength in ratio to size. Excessive functioning of the hypophysis at puberty seems to account for this condition. Later a second period of oversecretion (due to an infection?) perhaps coincident with a beginning tumefaction of the hypophysis produced acromegalic changes. Further growth of the struma caused severe headaches and optic compression and a secondary failure of hypophysial function, so that the final picture is one of hypopituitarism succeeding to the state of hyperpituitarism which had produced the most striking symptoms of this case.

(4) Acromegaly occurring in a hitherto normal adult may be illustrated by the following case quoted freely from Cushing (*The Pituitary Body and Its Disorders*, 1912, page 37). A woman aged 26 complained of amenorrhea, drowsiness, headache, polyuria and recent growth of hands and feet.

Analysis of hypophysial manifestations. (a) Neighborhood symptoms: sella enlarged (2.2 cm. antero-posteriorly by 1.5 cm. deep). Eyes: slight exophthalmos, bilateral ptosis, left oculomotor palsy with diplopia; bilateral (apparently primary) optic atrophy with superimposed choked disc; right homonymous hemianopsia with positive hemianopic pupillary reaction (Wernicke); left pupil larger than right.

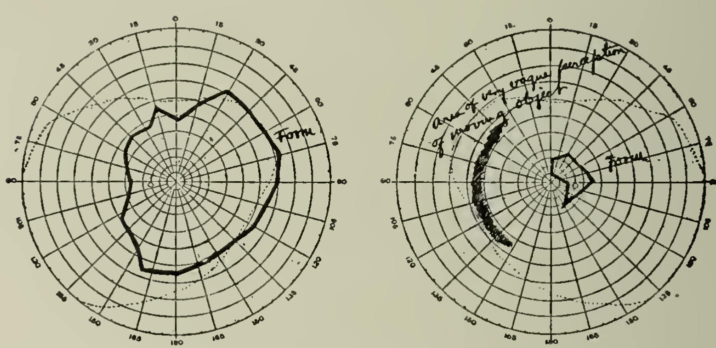
(b) General pressure symptoms: severe headache, nausea, vomiting; low grade of edema superimposed on discs showing atrophic pallor.

(c) Glandular symptoms: skeletal: skull not particularly modified, though malar and zygomatic arches are enlarged; jaw is not undershot nor are teeth spaced; no dorsal kyphosis; hands and feet are characteristically modified and X-ray shows typical bony changes. Cutaneous: enlargement of soft parts is more characteristic, especially of the nose, lips, tongue and extremities; width of nose is 4.5 cm., breadth of hand at knuckles 9.5 cm.; usual deep creasing of forehead, palms and

knuckles due to thickening of the tissues; hair thick and luxuriant; skin moist and much pigmented; dermatographia marked. Temperature above normal; tendency to polyuria; torpor and drowsiness marked; no increase of sugar assimilation.

Operation was performed (sellar decompression by the sublabial route). Death followed the next day from medullary failure. Necropsy revealed a glandular struma with cells of the chromophilic type indicating hyperplasia of the anterior lobe; degeneration of this tissue was taking place with an actively invading chromophobe struma.

This is a case of hyperpituitarism as shown by the acromegaly, luxuriant hair, moist skin, increased temperature and normal sugar tolerance. As is usual, glandular insufficiency was beginning to replace the condition of overactivity. The later signs of hypopituitarism often overshadow the previous condition of excessive pituitary functioning.



Hypopituitarism—eighteen days before operation.

Other cases are seen in which overactivity of the gland is not evident at any time or is inconspicuous, while the condition of hypopituitarism is conspicuous throughout. This type will be described in the (1) juvenile and the (2) adult forms.

(1) Hypopituitarism in its most typical form, the dystrophia adiposa-genitalis, is illustrated by the case studied by Wescott and Hill (*Archives of Ophthalmology*, vol. xlii, No. 4, 1913); an undersized sexually infantile boy, with slight adiposity, mental dullness and headache. Transient blindness occurred 3 years previously; the right eye was nearly blind, the left had ½ vision, there was primary optic atrophy, and temporal limitation of the visual fields. Evacuation of a cyst of the hypophysis effected a cure, with useful vision in one eye.

The contents of the cyst contained a pressor substance. Upon in-

jection into a dog weighing 3 kg. an increase of 20 mm. of mercury occurred and persisted more than one half hour. This case is a fairly typical example of the Fröhlich syndrome which Bartels called "dystrophia adiposo-genitalis": an underdeveloped, overfat boy with infantile sexual organs, entire absence of secondary sexual characteristics, and a history of polyuria, with eye symptoms suggestive of chiasmal disease (primary optic atrophy and visual field contraction chiefly on the temporal side). The early transient failure of sight is consistent with the cystic character of the growth found at operation. Severe headache, nausea and vomiting, polyuria, and glycosuria just before operation, are indicative of intracranial growth. The mass evacuated gave proof of a degenerative change in the hypophysis, including the pars anterior, and the pars intermedia (detritus; blood pressure rise on injecting the fluid into a dog). Polyuria, so frequent in cases of hypopituitarism, is difficult to explain in the light of experimental knowledge. Mechanical stimulation of the posterior lobe by the growth in front would account for stimulation of the renal epithelium; but the adiposity is believed to be the result of insufficient posterior lobe secretion. The glycosuria developing just before operation (when the patient was taking no food) was a transient phenomenon and cannot be explained as an evidence of posterior lobe stimulation, but as the result of the excessive intracranial pressure, as is found in many cases of brain tumor. The widening of the visual field after operation was mainly observed in the temporal half, being a reversal of the original process of narrowing characteristic of these cases.

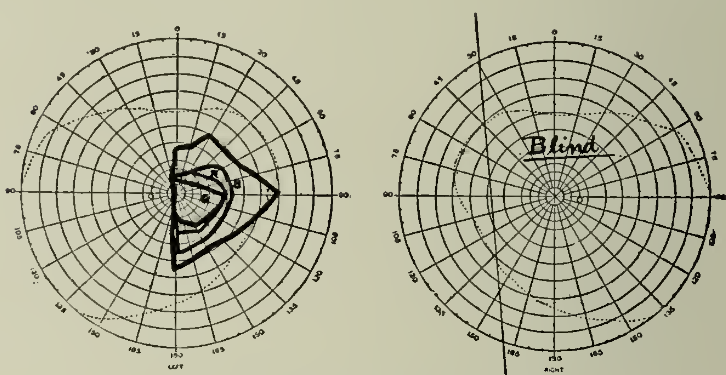
(2) Hypopituitarism developing in adult life is illustrated in the following case quoted from Cushing (*The Pituitary Body and Its Disorders*, pp. 58 ff.): January 2, 1911. Woman, aged 40. Complaint, headache, failing vision, amenorrhea and asthenia. Analysis of hypophysial symptoms. (a) Neighborhood: the X-ray is inconclusive. It shows possibly some downward displacement of the sphenoidal region. Eyes: slight exophthalmos, more in left than right; venules of lids full; pupils equal, reactions better from temporal than from nasal retinæ (positive Wernicke); fundi show primary optic atrophy on right with tortuous vessels but no edema; less pallor and some edema on left. No oculomotor disturbances; probable bitemporal defect. Partial anosmia; no uncinate attacks. Nasopharynx negative; no epistaxis. (b) General pressure symptoms: persistent temporofrontal headaches; slight obscuration from edema of nasal margin of left disc; no vomiting; dizziness. (c) Glandular: she has a small frame. Height 4 feet, 11 inches. Configuration of facial bones suggestive of sphenoidal

distortion; hands very short and stubby; nails show no crescents; slight suggestion of phalangeal exostoses apparent on X-ray.

Cutaneous: she is very dark-complexioned; the skin over the body and extremities is smooth and soft but without special pigmentation; pilosity of body (axilla and pubes) low but there is a growth of lanuga-like hair on the cheeks and lips; the hair of the scalp is dry and thin. Adiposity marked with some tendency toward lobulation, but no lipomata. Weight, 154 pounds.

Carbohydrate tolerance high; assimilation limit for levulose 300 grams. No anterior lobe thermic tests made. Temperature range subnormal (occasionally as low as 96.2); pulse variable (68-100).

Other ductless glands. Thyroid: both lobes palpable but not enlarged; no increase of retrosternal dullness. Amenorrhea for 5 months; a temporary mammary secretion from some hormone action (?).



Dyspituitarism—October 15, 1912.

Jan. 21, 1911. Operation was undertaken (sellar decompression by sublabial route); otitis media developed and orbital edema; nasal discharge persisted ten days; follicular tonsillitis; headache persisted; progressive loss of vision, colors being no longer recognized in left; acuity soon reached 1/100.

March 29, 1911. Right subtemporal decompression; marked cerebral tension; lumbar puncture (50 cc.). The fluid, concentrated to 2 cc., showed insignificant pressor response in a rabbit but caused glycosuria and diuresis. Headaches were alleviated but vision continued practically nil.

Condition stationary for three months with occasional headache. July 5, X-ray showed very thin-walled sella of normal configuration

in unusually low position, measuring 1.4 cm. by .9 cm. in depth. Organotherapy started; improvement quick; return of vision in right nasal field (August 28). September 4, first menstrual period in over two years. December 3, normal menstrual periods have continued.

The large group of cases of perverted pituitary function, neither exclusively hyper- or hypo-functioning, which Cushing has called "dyspituitarism," is illustrated in the case studied by Brown and Hill (*Archives of Ophthalmology,* vol. xlii, No. 4, 1913).

A boy aged 16 years complains of blindness in one eye and headache. He is blind in the right eye and has ½ vision in the left eye with a temporal hemianopsia; both discs are atrophic without any swelling.

Neurological study revealed the following: The boy is sturdy-looking, of medium height, well developed for his age (16 years). The features are heavy, hands and feet large; skin coarse and perspires rather freely. The face is covered with acne. The nose is very broad and the right half a trifle larger than the left. Some rather coarse tremors of outstretched hands and fingers, not intentional; some tremor of lips when he shows his teeth, and of the protruded tongue. The facial, auditory, and fifth nerves are not involved. The penis and testicles are large, the pubic and axillary hairs abundant. He has had no emissions, but frequent erections and sexual desire in the past year. Height 5 feet 5⅞ inches; feet 9⅝ inches long; weight 144 pounds. He thinks he has fattened ten pounds and grown one or two inches and become physically stronger in the past year.

X-ray pictures showed the sella not deepened but tilted backwards, and apparently an erosion of the bone just beneath the posterior clinoid process.[1]

Careful study for 33 days revealed a subnormal temperature and a high sugar tolerance, two conditions which Cushing has found to be such frequent accompaniments of the hypophysis disorders characterized by undersecretion that he believes them to be of diagnostic value.

This case is placed under the heading of "dyspituitarism," exhibiting a perversion of glandular secretion neither frankly overactive nor

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[1] Cushing states that "profile radiographic measurements exceeding 15mm. antero-posteriorly and 10 mm. in depth may be looked upon as indicating an enlargement." He quotes Arthur Keith (*Lancet,* 1911) to the effect that skeletal measurements of the sella reveal an average of 10 to 12mm. antero-posteriorly, 14 to 15mm. transversely, and 8mm. in depth.

Otis H. Maclay of Chicago has published (*Laryngoscope,* September, 1911) careful measurements from dried skulls as follows: inter-carotid distance, 14 cases average 9.2mm.; width (between carotid grooves), 20 cases average 11.4mm.; depth of sella, 42 cases average 7.6mm.

underactive. Temporal hemianopsia of the left eye points conclusively to pressure at the chiasm, and the abducens paresis and blindness of the right eye are consistent with this diagnosis. The X-ray pictures are not definite but are suggestive of pressure upon the body of the sphenoid from above. That the hypophysis has been functioning excessively is indicated by the appearance of over-development for a boy of 16 years; heavy features, large extremities, coarse, perspiring skin, and somewhat precocious sexuality. The stationary vision and general comfort, aside from headaches, for the past year point to a cessation of growth in the tumor. Low temperature and increased carbohydrate tolerance indicate that the hypersecretion of the hypophysis has now been replaced by a hyposecretion, and acromegalic changes are not to be anticipated. A tumor in the region of the hypophysis pressing upon the hypophysis secondarily, seems the likliest explanation of the symptom-complex here seen. The history of injury is remote and possibly not in reality connnected with the symptoms of recent years.

Operation was not advised in this case, because the growth was believed not to be so accessible as a primary tumor of the pituitary body would be as in the first case of hypopituitarism cited and because the symptoms were not progressing and there was no danger of acromegalic changes since the gland was in a state of deficient secretion. The outcome with or without treatment is uncertain, and no very hopeful prognosis is justified.

Changes in the optic nerve heads and alterations in the visual fields are the conspicuous visual defects observed in pituitary disease. Other disturbances of the visual organs occur because of the anatomic relations of the hypophysis and the frequent increase of intracranial pressure from tumor formation and hypdrocephalus, but these are of less diagnostic importance than the evidences of direct pressure upon the optic chiasm. Bony enlargement of the orbit, thickening of the lid tissues, hypertrophy of the lid glands, warty growths and pigmentation of the lids are observed in hyperpituitarism, especially with acromegaly. *Exophthalmos* occurred in 8 per cent. of Uhthoff's acromegalic cases and Cushing found a larger proportion of exophthalmos in his cases of hyperpituitarism not all of which were acromegalics. Stasis in the cavernous sinus seems the most likely explanation of this phenomenon. Hypertrophy of the orbital fat is also suggested as a cause.

Ocular muscle palsies occur more frequently with the rapidly growing tumors associated with deficient hypophysial function than in

acromegaly. Thus Uhthoff (*Transact. 16th Int. Med. Congress,* Budapest, 1910) records muscle palsies in ten per cent. of acromegalics and in twenty-five per cent. of his series of tumors without acromegaly. Ptosis, diplopia and pupillary inequalities are observed. The third nerve is most frequently involved; next in frequency is the sixth nerve; the fourth is least often involved.

Ophthalmoplegia is infrequent. When exophthalmos is absent ocular muscle palsies can be better explained by pressure effects at the base of the brain than by encroachment upon the cavernous sinuses. Nystagmus is an occasional appearance not attributable to the hypophysial lesion directly but the result of remote intracranial tension.

Primary optic atrophy is the most frequent optic nerve lesion in pituitary disease. Tumor formation at the chiasm compresses the sheath of Schwalbe and prevents the passage of cerebro-spinal fluid along the intervaginal spaces so that the papillitis usually associated with brain tumors is infrequent. Extensive growths of the hypophysis usually result in destruction of the glandular function with the resulting condition of hypopituitarism, so that primary atrophy is more frequent in this type. Cushing found primary atrophy in 15 cases of hypopituitarism and in only 3 cases of hyperpituitarism in a series of 36 cases. He found *choked disc,* on the contrary, in 5 cases of hyperpituitarism and in no case of hypopituitarism. Choked disc superimposed upon a primary atrophy was observed only once in hyperpituitarism in contrast to 9 times in hypopituitarism. *Secondary optic atrophy* was noted 3 times in hyperpituitarism in the same series, and once in hypopituitarism.

Visual field limitations have long been recognized as important indications of pituitary enlargement. In pre-ophthalmoscopic days hypophysis disorders were recognized late, and chief emphasis was laid upon the very striking picture of *bitemporal hemianopsia* which was described by Mackenzie in 1835 and later by von Graefe. Only a lesion in the mid-line pressing upon the optic chiasm could cause such a field, and only such a clean-cut evidence of a lesion at this location would suggest the pituitary body in the days before the modern understanding of the ductless gland functions. It represents a late stage of involvement of the opticus when but little may be expected from surgery. Moreover, statistics do not reveal so large a preponderance of this defect as might be supposed from the anatomic situation of the hypophysis.

Uhthoff has recorded the following large series of cases (*Trans. 16th Int. Med. Congress,* Budapest, 1910):

	207 cases with acromegaly	*121 cases without acromegaly*
Amblyopia and amaurosis	15 cases	34 cases } mostly in pre-ophthalmoscopic days.
Temporal hemianopsia	89 cases	37 cases } mostly in pre-ophthalmoscopic days.
Homonymous hemianopsia	9 cases	2 cases
Choked disk	11 cases	15 cases
Optic neuritis	11 cases	14 cases
Optic atrophy	40 cases	27 cases
Retinitis	2 cases	
Chronic iritis	1 case	
Cataract	2 cases	
Peripheral visual field contraction.		3 cases
Central scotoma		3 cases
Anatomically proven compression at the chiasm without visual disturbance		12 cases (often with anosmia)

Bartels reported the following 22 cases (*Zeit. f. Augenheil.*, Bd. xvi, 1906):

Bitemporal hemianopsia	23 per cent.
Unilateral temporal hemianopsia	23 per cent.
Homonymous hemianopsia	9 per cent.
Concentric contraction	22 per cent.
Irregular contraction	4 per cent.
Sector-shaped contraction	9 per cent.
Central scotoma	13 per cent.

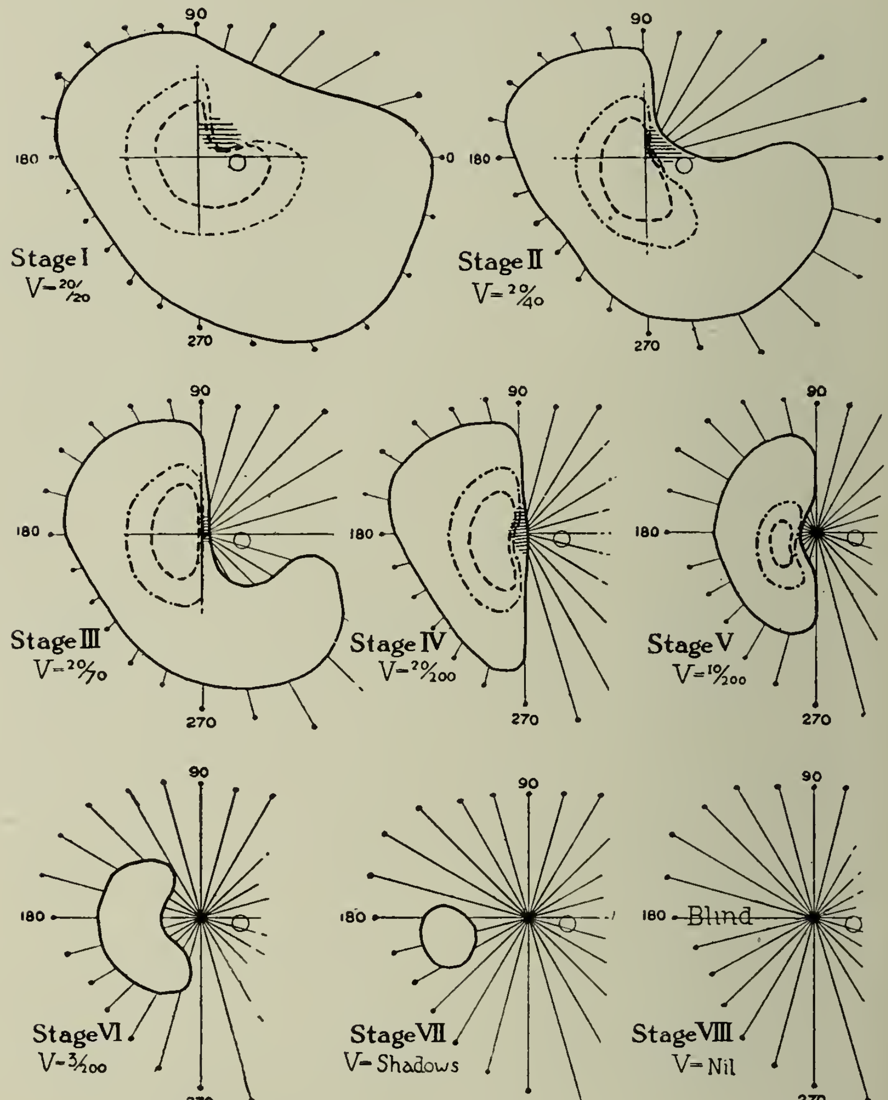
Thus Bartels found temporal hemianopsia in 46 per cent. of his cases, and Uhthoff in 38 per cent. In Cushing's series of brain tumors in which hypophysis cases predominated, only one-third of the visual field limitations were of the type of temporal hemianopsia. Of 81 hypophysis cases, Cushing (*Brain*, 1915, vol. xxxvii) placed 26 in the group of bitemporal limitation. This represents the most thoroughly studied group of cases in the literature today with distinct refinements in the charting of fields of vision, and it is to be noted that this classification includes tendencies to bitemporal blindness and is not limited to the clean-cut hemianopsias pictured in the text-books. This observation suggests the further fact that pressure effects from enlarging tumefactions in the region of the chiasm are progressive. Cases are seen in which blocking of the light impulse is revealed by slight contraction in the peripheral field, and a series of charts will show the steadily advancing contraction in the direction of a hemianopsia. Cushing has described such a progressive involvement as follows: "The primary defect usually involves the color boundaries alone in one upper temporal quadrant. This is followed by a more or less complete hemiachromatopsia, possibly with a slant in the upper temporal form field, which gradually spreads downward until most of the temporal field is involved. In all cases the color fields are involved first, the form fields later. The macular area is often spared for a long time, but finally it becomes implicated in turn, first in its temporal

half; finally the whole central area enters the blind field, and the nasal half in turn progressively shrinks away from the centre. It is to be emphasized that rarely are the two eyes affected in equal degree, and also, that after operation, restorations occur in reverse order."

The tumors of the gland proper, pressing upwards, are the most frequent causes of this characteristic visual field limitation, but supra-sellar (interpeduncular) tumors may do the same. The latter, usually cystic, originating in a pharyngeal anlage, are, in Cushing's experience, generally of slow growth with few symptoms and are likely to escape detection until pressure upon the chiasm has produced a bitemporal blindness.

Cushing has classified the progressive narrowing of the fields into eight stages with a degree of correspondence between central vision and peripheral involvement. He cautions against conceiving of this as a static thing since the process does not stand still at any stage, except possibly when a temporal hemianopsia has been reached and further loss may be delayed for a time.

To summarize, it may be said that bitemporal hemianopsia is a late and comparatively infrequent manifestation of hypophysial lesions and that tendencies towards temporal hemianopsia, especially for colors, are frequent and important findings, so that slight defects in the upper temporal fields are to be regarded as early signs of pituitary disorder leading to other studies of the glandular function and X-ray examination of the sella turcica which may substantiate the suspicion of hypophysial enlargement at a time when operative interference may save vision. Due consideration should be given to the observation of Cushing and Walker (*Brain*, vol. xxxvii, p. 343): "A bitemporal hemianopsia, or a tendency in this direction, is by no means the necessary expression of chiasmal involvement when vision does become affected by a hypophysial lesion; for nearly half as many cases in the series have shown an equally definite homonymous hemianopsia or a tendency in that direction. In its so-called typical form, furthermore, with a practically vertical meridian which sharply divides in each eye the blind nasal from the seeing temporal retina, a bitemporal hemianopsia is far from the most common form of field defect. Hence a conclusion that an existent clean cut bitemporal hemianopsia is an evidence of a medial lesion, most often due to a tumefaction of the hypophysis or its stalk, is justifiable enough; but the reverse argument does not hold—that the absence of this characteristic defect, or indeed of any defect whatsoever in the fields, necessarily speaks against a primary pituitary or interpeduncular growth."



Showing the eight stages of a progressing right temporal defect. (Cushing and Walker: *Brain,* vol. xxxvii, March, 1915). Primary dotted outline in Stages I-V, red; secondary dotted outline, blue.

Homonymous hemianopsia is less frequent in a series of cases in which hypophysial lesions predominate than in a series of brain lesions without such bias. Cerebral vascular lesions are the most frequent source of such a visual field limitation; yet Cushing has observed in post-mortem studies that the optic tracts usually suffer more from hypophysial pressure than the optic nerves or chiasm. His group of 81 cases, already referred to, contained 12 examples of this type of blindness. As in the case of other less typical visual field contractions, the important consideration here is that pituitary lesions should not be excluded because the classic form of bitemporal hemianopsia does not exist.

Inferior and superior hemianopsia, quadrant defects, interlacing color fields, blindness in one eye, with or without a history indicative of a definite type of hemianopsia preceding, may occur from the pressure of hypophysial growth or a neighboring lesion upon the tracts or nerves near the chiasm.

Binasal hemianopsia is quite naturally infrequent, as two symmetrical lesions such as must be postulated for a clean-cut hemianopsia corresponding to a destruction of each uncrossed fasciculus are improbable occurrences. As long ago as 1873 H. Knapp suggested sclerosis of the internal carotid arteries as a possible source of bilateral compression upon the sides of the optic chiasm. Tabes, fracture of the base of the skull, and syphilitic processes about the chiasm have also been advanced as causes of binasal defects. Cushing and Walker have contributed a valuable study to this subject (*Arch. of Oph.,* Vol. XII, No. 6, 1912). In a series of 300 cases of brain tumor 5 to 6 per cent. showed a tendency to binasal hemianopsia. This defect may be found in those cases of secondary pressure effects upon the hypophysis by growths elsewhere in the cranial cavity through the intervention of a hydrocephalus. They are generally subtentorial growths but may be cerebral. These authors present several important observations: generally the neuro-retinal lesion was greater on the side of the brain lesion, "but when hydrocephalus has been produced the changes tend to increase by equal steps in each eye." "An advanced grade of choked disc, often the sequel of an obstructive hydrops of the ventricles, has been shown to be the forerunner of the binasal blindness." Such a field limitation occurring as a "late sequel of an advanced choked disc in the stage of recession of the edema, and a bilaterally symmetrical process, implying an equal degree of involvement of the two eyes, suggests as a rule a distant, often cerebellar, lesion with secondary hydrocephalus." The following theory is advanced to explain the

origin of this peculiar mode of optic compression: "An internal hydrocephalus with distension of the third ventricle crowds the optic nerves downward and outward against the carotid vessels which transversely indent the outer aspect of the nerves. In this way the uncrossed fasciculi to the temporal retinæ, and the laterally placed macular bundle as well, suffer from a mechanical pressure 'block' in addition to the diffuse anatomical destruction of fibres throughout the nerve in consequence of the contraction of the new tissue formation in the long-standing choked disc." This theory would seem to be substantiated in some cases by the relationships observed in brains hardened in situ.

The color fields are especially important in pituitary lesions since they suffer before the form field. Cushing's observation, already quoted, is that the early loss of colors in the upper temporal quadrant points to chiasmal pressure, being the precursor of a hemiachromatopsia which is in turn followed by a temporal hemianopsia. J. Herbert Fisher (*Trans. Oph. Soc. Unit. King.*, 1911) has emphasized the importance of the loss of color fields as an index to the progress of pituitary disease. Cushing has called attention to interlacing of color boundaries in brain tumors including pituitary growths. Daily variations in color as well as form fields are frequently observed, as has been especially emphasized by de Kleijn (Graefe's *Arch. f. Oph.*, lxxx, p. 307).

Scotomata have been found with increasing frequency as more careful methods have been employed for charting visual fields. In the earlier literature they were so rarely mentioned that their presence was regarded as scarcely compatible with a pituitary lesion. Uhthoff recorded only three scotomas in 328 cases. More recently numerous writers have emphasized the frequency of scotomata, notably Patrick and de Schweinitz and Holloway (*Trans. Section on Ophthal., A. M. A.*, 1912). The latter authors present the following classification: 1. Small and paracentral scotomata. 2. A quadrant up and out. 3. Scotomata varying in size and position. 4. Bitemporal hemianopic scotomata. 5. Scotomata in the temporal field at some distance from the fixation point. 6. Blurred vision, unexplained by any ophthalmoscopic lesion.

These observations have been confirmed by Cushing and Walker in a large series of cases. The special vulnerability of the macular fibres leads to early scotoma with peripheral vision embracing the more centrally located blurred area which may be included later in the blind field. If post-operative widening occurs the peripheral field may again

enclose a scotoma which does not entirely disappear because the highly specialized macular fibres are not capable of complete restoration of function.

In studying the literature of pituitary disease one meets at every hand the names of Cushing and Walker. It is the ophthalmologist's pleasant duty to acknowledge his very great debt to Harvey Cushing who has illuminated the subject from every standpoint by his brilliant investigations and epoch-making surgery and to Clifford B. Walker who has made valuable contributions to our knowledge of the visual fields in pituitary disease through his painstaking researches with specially devised instruments which secure a greater accuracy in perimetry than was hitherto possible.—(E. H.)

See, also, **Hypophysis,** p. 6117, Vol. VIII; **Hemiopia,** p. 5766, Vol. VIII; **Acromegaly,** p. 79, Vol. I, as well as **Brain tumor,** and **Perimetry,** this *Encyclopedia.*

Pituri plant. See p. 4087, Vol. VI of this *Encyclopedia,* under **Duboisin.**

Pityriasis pilaris. See **Keratosis pilaris.**

Pix liquida. See **Tar.**

Placentapepton. A proprietary preparation of peptone derived from the placenta and used for Abderhalden's optical test for pregnancy.

Placidoscope. See **Astigmatoscope;** also **Keratoscope,** and **Placido's disc.**

Placido's disc. Placido's keratoscope. Astigmatoscope. See p. 659, Vol. I and p. 6834, Vol. IX of this *Encyclopedia.*

Placode. A thickened plate of ectoderm forming the anlage of an organ in the embryo, as the ear.

Pladarosis. Pladarotes. An old term for a soft, moist, non-inflammatory swelling on the conjunctival surface of the eyelid.

Plague, Ocular relations of the. The common form of this epidemic disease is a malignant and highly contagious polyadenitis known as the bubonic plague. It is probably a rat-borne disease and accompanies filth and famine. See p. 1322, Vol. II of this *Encyclopedia.*

Th. Wernecke (*Viestnik Oftalm.,* Feb., 1911; abstracted in *Oph. Review,* p. 331, Nov., 1911) describes three cases in which eye affections developed. In all of them there was iritis and a slight amount of cyclitis, and in one there was also found optic neuritis. All three recovered.

The author, from a survey of the literature and as a result of his own observations, comes to the following conclusions:—

1. Ocular affections have been observed as the first focus of infection once in the form of acute dacryocystitis and five times in the form

of an acute conjunctivitis resembling the gonorrheal form with rather less abundant secretion and with the admixture of blood.

2. From such foci of infection the whole organism is readily infected without the necessity of any skin abrasion.

3. As complications in plague cases there have been observed panophthalmitis, irido-cyclitis, iritis, keratitis (with and without hypopyon), corneal ulceration, conjunctivitis, and once (the author's case) optic neuritis.

4. The ring-shaped ulcer and all the cases that terminated in loss of the eye from panophthalmitis have been shown to contain the bacillus of plague.

5. Optic neuritis, iritis, irido-cyclitis, and keratitis (non-ulcerative) are probably caused by circulating toxins and give for the most part a good prognosis.

6. The eye complications appear soon after the general affection, usually from two to five days after the onset.

7. Among the 601 cases of plague collected by Myzuo there were 26 with ocular affections (about 4.3 per cent.), while at Odessa the author found three cases in 140 (about 2 per cent.).

8. Werncke is unable to confirm Mizuo's statement that conjunctival congestion is a constant symptom of plague.

Planary. Flat; lying in one plane.

Planchette d'objectif. (F.) Camera front.

Plan du foyer. (F.) Focal plane.

Plane, Daubenton's. A plane in which are the opisthion and the lower edges of the orbits.

Plane-field. In *optics,* the totality of all the points and straight lines situated in an infinitely extended plane in any meridian containing the optical axis of a lens-system. See, also, **Collinear space-systems.**—(C. F. P.)

Plane, Listing's. A transverse vertical plane which is perpendicular to the antero-posterior axis of the eye, and which contains the center of motion of the eyes; in it also lie the transverse and vertical axes of voluntary ocular rotation.

Plane of polarization. See **Polarization.**

Plane of reference. See **Muscles, Ocular.**

Plane of regard. A plane passing through the center of rotation of the eye and the fixation point.

Plane of rotation. See **Muscles, Ocular.**

Plane, Orbital. The orbital surface of the maxilla; also the plane that passes through the visual axis of each eye.

Plane-plane. Having two plane surfaces parallel to each other.

Plane polarization. The restriction of the vibrations of the ether to which a ray is due to a single plane.

Planes, Focal. Two planes drawn respectively through the anterior and posterior principal foci of a dioptric system (e. g., the eye) and perpendicular to the line (axis of the system) connecting the two. The plane passing through the anterior focus is called the anterior (or first) focal plane; that passing through the posterior focus the posterior (or second) focal plane.

Planes of separation. These are three in number: (1) the *horizontal* plane divides the globe into an upper and lower half; (2) the *vertical* plane divides it into an outer and an inner half, while (3) the *equatorial* plane divides the eyeball into an anterior and a posterior half.

Planes of unit magnification. See **Cardinal points of a lens.**

Plane tree, The. The leaves of the plane tree, in ancient Greco-Roman times, were often employed as a poultice in any affection of the eye accompanied by great pain.—(T. H. S.)

Plane, Van Ihering's. A plane tangent to the lower margin of the orbit and passing through the auricular points.

Plane, Visual. A plane passing through the visual axis.

Planimeter. An instrument for the measurement of plane areas.

Plano-concave lens. A lens with one plane and one concave surface. See p. 7240, Vol. X of this *Encyclopedia.*

Plano-convex lens. A lens with one plane and one convex surface. See p. 7240, Vol. X of this *Encyclopedia.*

Plano-orbicular. Plane on one side and spherical on the other.

Planosubulate. Smooth and very acutely conical.

Plantago. Plantain. Ribgrass. Ripplegrass. Ribwort. The whole plant of *Plantago major* is used in medicine. It contains tannin, like so many herbs employed in ophthalmic therapeutics, and is prescribed as compresses and eye lotions in the form of the aqueous extract or infusion in subacute and chronic forms of conjunctivitis. It is also made into "tea" for the same purpose, like chamomile, Clary sage and similar astringent, herbaceous remedies.

Plantain juice (of *Plantago major*), in ancient Greco-Roman times, was highly esteemed as a remedy for lippitude. The leaves mingled with salt were also employed for ægilops (lachrymal fistula).—(T. H. S.)

Plantanus occidentalis. This remedy was, by W. H. Williams (*Jour. Ophthal., Otol. and Laryngol.,* March, 1916), given internally in from one to three drop doses (of the tincture?) about two or three times daily for the absorption of chalazion. He reports five cases, two in young children and three in adults. The chalazia in the children dis-

appeared after the drug had been used for several months. In adults its use had apparently but little if any effect.

We suggest to the experimenter that his ill-success with adult patients was due to the fact that the "yarb" was not collected—as it ought to have been—by the pale light of the moon!

Plantar reflex. This is the Babinski sign or phenomenon, an involuntary, deliberate (occasionally sharp) extension or hyper-extension of the great toe, frequently associated with a fan-like spreading of all the toes in response to a tickling or stroking form of stimulation applied to the sole of the foot. The normal response to plantar stimulation is flexion of all the toes. The extensor plantar reflex (Babinski phenomenon) is, therefore, practically always an evidence of organic disease of the central nervous system involving the pyramidal tracts somewhere throughout their extent in the brain or spinal cord. It is not present in uncomplicated hysteria. It is a sign of great importance in distinguishing organic from functional disease of the nervous system. A positive Babinski is observed in epilepsy immediately following the convulsive seizure and it has been recorded as present after the administration of hyoscine (scopolamine) in medicinal doses. —(D. H.)

Plants, Eyes of. Macdougal, Harold Wager and Prof. Haberlandt are quoted by the *Scientific American* (Oct. 17, 1908) on the subject of the sensitiveness of plants to light. The upper and lower surfaces of leaves are covered by a thin, transparent skin, which can, in many cases, be very easily peeled off. When examined under the microscope this skin is seen to consist of innumerable compartments or cells, many thousands of which are found on a single leaf. They contain a clear, watery sap, and their shape is such that they behave like ordinary convex or plano-convex lenses, the rays of light which fall upon them being converged and brought to a focus in the substance of the leaf. These cells probably enable the plant to perceive the difference between light and dark, and set up a stimulus which results in the movement of the leaf into such a position that it can obtain the maximum amount of light; or it may be that they serve for the more efficient illumination of the green grains within the leaf upon which the effective food supply of the plant depends. Possibly both play some part in aiding the leaf to perform its work more efficiently. These cells are found in practically all plants. In many cases these lens-cells may be compared with the corneal facets of an insect's eye, so far as their general appearance and power of causing a convergence of light are concerned.

Plasma. See **Artificial blood serum.** See p. 620, Vol. I of this *Encyclopedia;* also **Glycerite of starch,** p. 5593, Vol. VII.

Plasma cells. These corpuscles or cells are found in lymph or in the fluid portions of the blood. They occur normally in various mucous membranes and in normal lymphoid tissues, as well as in pathologic deposits and new growths. The basic dyes stain them readily; the protoplasm is not granular and is less dense in the center than at the periphery. The nuclei contain much chromatin arranged in a characteristic manner.

Plasma cupri sulphatis. A preparation of the Royal London Ophthalmic Hospital containing 45 parts of glycerin and 12 parts of copper sulphate.

Plasmocytoma. This term is loosely applied (1) as a synonym of plasmoma and (2) to indicate a *myoma* made up largely of plasma cells.

Rund (*Zeitschr. f. Augenheilk.*, xxvi, p. 97, 1913) describes under the caption, *Plasmocytoma of the conjunctiva*, a growth in the left upper lid of a man of fifty-one years. It had first appeared seventeen years earlier, and had twice recurred after excision. Microscopic section of a part of the growth showed it to consist almost entirely of plasma cells. There was absolutely no indication of a chronic inflammatory process. Plasma cells were found not only arising from the blood vessels next to the growth, but around vessels at some distance from it. The tumor is therefore to be regarded as analogous to a lymphoma.

Under the same name Kuboki (*Ophthalmology*, p. 545, April, 1917) describes a tumor in a 27-year-old woman at the inner canthus, that covered the cornea. The pre-auricular and cervical glands of the same side were enlarged. The tumor consisted of plasma cells grouped in follicles; the interstitial tissue was mostly fascicular but in places, much thickened. See, also, p. 3055, Vol. IV of this *Encyclopedia.*

Plasmodium malariæ. This is the hematozoon of fever and ague, the parasite that exists in the red corpuscles in various forms of malaria. It develops originally in the bodies of mosquitoes of the genus *Anopheles*, being transmitted to man by the bite of these insects. See p. 9271, Vol. XII, as well as p. 7868, Vol. X, of this *Encyclopedia.* Consult also **Malaria.**

Plasmoma. A term introduced in 1908 by Pascheff (see p. 218, Vol. I of this *Encyclopedia*) to describe a form of hyaloid growth of the conjunctiva, but now commonly used to define a tumor largely constructed of plasma cells. See, also, **Plasmocystoma.**

Plasmoma of the conjunctiva. In 1874, Waldeyer introduced the term plasma cells for certain cells of the connective tissue. Von

Marschalkó attributes their origin to the lymphocytes of the blood, which Rados (*Zeitschr. f. Augenheilk.*, Feb., 1913) considers most probable. Normally, they occur in the bone marrow, spleen and lymphatic glands. The two cases reported by the writer were characterized by lobular form and smooth surface, and were located in various portions of the conjunctiva, chiefly in the retrotarsal folds. Besides plasma cells, they contained numerous polynuclear leucocytes and lymphocytes, which indicated their local inflammatory nature. This was confirmed in both cases, especially in the first, which showed trachoma in the cicatricial stage and pannus.

In the case reported by Nakano (*Ophthalmic Year-Book*, p. 107, 1916) a man 30 years of age, complained of a gradual spontaneous drooping of the upper lid. There was a tumor-like thickening of the conjunctiva of the lid. Microscopically it was found to be composed of plasma cells.

Plasmoma of the lachrymal sac. Verhoeff and Derby (*Archiv. of Ophthal.*, May, 1915) record what they believe to be the only case of plasmoma of the lachrymal sac yet reported. There have been nine cases of plasmoma of other parts of the ocular structures. They consider that this condition "does not form a pathological entity, but simply represents an early stage of the disease known to previous writers as hyaline and amyloid degeneration of the conjunctiva, of which some 90 cases appear in literature." The pathological picture varies to an extraordinary extent, according to the stage at which the growth is removed. The very early cases show nothing but plasma cells with little or no degeneration, whilst the late ones are characterized by the deposit of large quantities of hyaline or amyloid material. These deposits represent a purely local condition, and are not associated with the general amyloid degeneration of wasting diseases. The writers favor the view that the condition is inflammatory rather than neoplastic. The connection between it and trachoma is held to be more than accidental. See, also, p. 6934, Vol. IX of this *Encyclopedia*.

Plasmoma, Aleukemic. See **Aleukemic plasmoma.**

Plaster. Emplastrum. Plasters are a class of medicinal agents consisting of "adhesive substances, spread upon leather or cloth, so as to stick to the part of the body to which they are applied." The most important are lead plaster, or diachylon, which enters into the composition of many of the others; resin and pitch plasters; belladonna and opium plasters; and cantharides or blistering plaster. Some of the most tenaciously adhesive of plasters (not in the Pharmacopeia) are made with preparations of india-rubber. Court, or sticking, plaster,

for dressing slight wounds, consists of a thin layer of isinglass spread upon silk.—(*Standard Encyclopedia.*)

Plastic choroiditis. See p. 2147, Vol. III of this *Encyclopedia.*

Plastic cyclitis. PLASTIC IRIDOCHOROIDITIS. The usual form of iridochoroiditis, characterized by circumcorneal injection, sensitiveness to pressure, discoloration and sluggishness of the iris, cloudiness of the aqueous humor, opacities in the vitreous, either fixed or floating, and marked failure of vision. See p. 3621, Vol. V of this *Encyclopedia.*

Plastic iritis. See p. 6649, Vol. IX of this *Encyclopedia.*

Plastics. The physical reconstruction of the ocular tissues, mainly by transplantation of skin, mucous membrane and other tissues from the same body (*autoplasty*) or from extraneous sources (*heteroplasty*), has been fully described under various captions in this *Encyclopedia.* See, for example, **Military surgery of the eye,** p. 7706, Vol. X; **Injuries of the eye,** p. 6200, Vol. VIII; **Injuries of the orbit,** p. 9122, Vol. XIII; **Conjunctivoplasty,** p. 3508, Vol. V; **Entropion,** p. 4331, Vol. VI; **Blepharoplasty,** p. 1040, Vol. II; **Grafting,** p. 5628, Vol. VII, and **Operations on the orbit,** p. 9147, Vol. XII. See, also, **War, Ophthalmic medicine and surgery in.**

Charles Higgens (*Lancet,* Oct. 7, 1916); abstract in *Br. Jour. of Ophthal.,* p. 60, Jan., 1917) has had a considerable amount of experience in plastic surgery of the face in connection with war wounds. He soon began to recognize the want of a material which would make up deficiency of bone, fill up cavities, and level up depressed cicatrices. Paraffin was tried, but was not of great value, because of its tendency to "wriggle out of the position it was placed in." Deformity was but little improved. Celluloid was then tried, and experience has proved its value. Higgens has used plates of celluloid for replacing bone, and solution for filling cavities and raising deep cicatrices. For placing beneath cicatrices, Higgens, who formerly used plates for this purpose also, has now replaced the celluloid plates with a solution. There are two solutions, the one of a solution of celluloid in acetone, the other a secret trade preparation invented for making corks water-tight. The latter is to be preferred. The method adopted is to make a tunnel under the cicatrix (subcutaneous detachment of the cicatrix) and then to inject the semifluid celluloid into the tunnel by means of a syringe with a screw-down piston. The syringe having been removed, a collodion dressing is applied to the wound. Major Pailing, a colleague of the author, has recently closed an opening in the skull with a celluloid plate. "The edges of the plate, which was curved to correspond with the curve of the skull, were pushed between the bone and dura and covered by the scalp." The result of this operation seems to

have been excellent. Higgens considers there is a great future before the "celluloid operation."

Another recent contribution to ocular plastics is the experience of Snydacker (*Ill. Med. Jour.*, Sept., 1916) who has found the ordinary operations for cicatricial ectropion unsatisfactory. He has devised a method which has given him satisfaction in a number of cases. In most operations the pull of the shrinking tissue is away from the eyeball, consequently flaps must be made redundant. It is difficult to nicely approximate a redundant flap. Snydacker thinks there is little danger of overcorrecting by his method. The chief objection to the operation is that it destroys the outer angle of the eye, though, as the author states, in a severe case there is a destruction of the outer angle anyway. It is best to give the technique in the author's own words: "Assuming ectropion to be in the lower lid, incision beginning just within the outer angle one-half centimeter below lid border and parallel with it; adhesion carefully dissected out. With a keratome that part of upper lid about 2 or 3 mm. above the outer angle split into two layers, skin being loosened back as far as orbital fold, outer angle included; loosened skin at outer angle of upper lid forms the pedicle of the flap; tongue of the flap is formed by two parallel incisions, semicircular in shape, parallel as much as possible to lower lid border. The flap is continuous in shape and contour with skin of upper lid; as much as possible where the scar tissue which is causing the ectropion extends beyond outer angle of lid, this must, of course, be included in the flap. I have never, however, experienced any trouble from this fact. The hair bulbs of the eyelashes at outer portion of upper lid are destroyed by cutting off with small curved scissors. The defect in lower lid is put on stretch by suturing edges of two lids together. The semi-circular flap without distortion of pedicle is easily laid into defect and sutured into place. If an especially nice and snug approximation is desired, we can pass a double armed suture through the conjunctival surface, each needle passing out through the outer skin surface of the flap and tied over small gauze roll, pressing the skin snugly against the underlying surface. The lids are kept sutured together, if possible, for several weeks." The operation attempts to follow the lines of Nature; the flap follows the lines of the orbicularis. What shrinkage takes place pulls the everted lid towards the eyeball. The defect made where the graft is taken can be covered in by undermining and approximation or by Thiersch graft.

Plastics, Conjunctival. See **Plastics.**

Plastograph. A picture constructed in a way to bring out a stereoscopic effect, when looked at through colored glasses. The picture is

made as follows:—the right-hand borders of most of the objects in the picture are colored red, and the left-hand borders green. The observer looks at the picture through a pair of spectacles which has a red glass over the right eye, and a green glass over the left; the stereoscopic effect is thus brought out clearly. A series of plastographs in book form is published by Max Skladanowsky, which he calls *Platische Weltbilder*. Each book is supplied with a card-board frame containing red and green colored celluloid or mica films, through which the pictures are observed.

Under the title "A Simple Plastograph," O. Zoth (*Zeitsch. f. Sinnesphys.*, 45, p. 85, 1915) draws attention to the well-known method employed by artists of looking at plane pictures with one eye through the hand closed like a tube, which has three advantages, viz.: greater brightness, greater distinctness and plastic appearance. The two first advantages can be easily explained by the exclusion of lateral and cross lights. Zoth explains the plastic effects by the exclusion of the surroundings of the picture, which furnish a number of elements for rendering the planeness of the picture more striking. If they are eliminated the motives in the picture for a conception of the represented third dimension are fully and without disturbance called into action and produce a surprising plastic effect. On this principle the writer constructed his plastoscope, which consists of a tube 8 cm. long, blackened inside, with an eye piece shaped for application to the orbital margin.

Platanus occidentalis. See **Sycamore.**

Plate box. A box designed to exclude light, for the storage of photographic dry plates.

Plate, Orbital. The process of the frontal bone that forms the roof of the orbit; the plate of the ethmoid bone that forms the greater part of the inner wall of the orbit; the orbital process of the superior maxillary bone.

Plater, Felix. A professor of medicine at Basel, who was born in 1536 and who died in 1614. He was the first to declare explicitly that the images of objects in the external world (after being distinctly produced by the lens) were received upon the retina. The function of the lens as the image-forming portion of the eye, had been correctly determined, just a few years previously, by the mathematician, Maurolycus, but Maurolycus had not definitely and positively conceived the idea of the screen-like function of the retina. This was done by Plater, who even proceeded a little further, declaring that the retina was the essential portion of the visual apparatus.—(T. H. S.)

Plate, Tarsal. The quasi-cartilaginous substance which gives firmness to an eyelid.

Platine. (F.) Stage.

Platine à chariot. (F.) Mechanical stage.

Platitude des champs. (F.) Flatness of field.

Platner, Johann Zacharias. A well-known anatomist, surgeon and ophthalmologist, of Leipsic, Germany. Born Aug. 16, 1694, at Chemnitz, he studied his profession both at Leipsic and at Halle. In 1721 he was appointed extraordinary professor of anatomy and surgery at Leipsic, and, three years later, received the ordinary appointment to the chair of these, as well as to certain other branches in the same institution. He was also for a long time dean of the faculty. He died Dec. 19, 1747.

An excellent operator, he was also a clear and forceful writer. His ophthalmic compositions are as follows:

1. Diss. de Fistula Lacrimali. (Leipsic, 1724.)
2. Diss. de Scarificatione Oculorum. (Leipsic, 1728. Really a revival of ancient methods.)
3. De Chirurgia Ocularia. (Leipsic, 1735.)
4. De Motu Ligamenti Ciliaris in Oculo. (Leipsic, 1738. Contends that the ciliary body performs motor and secretory functions.)
5. De Vulneribus Superciliis Illatis, cur Caecitatem Inferant, ad Locum Hippocratis Proprium. (Leipsic, 1741.)
6. De Noxis ex Cohibita Suppuratione in Nonnullis Oculorum Morbis. (Leipsic, 1742.)
7. Jo. Zach. Platneri, D. et Prof. Med. Lips. Institutiones Chirurgicæ Rationalis tum Medicæ tum Manualis in Usus Discentium. Adjectæ sunt Icones Nonullorum Ferramentorum Aliarumque Rerum, quæ ad Chirurgi Officinam Pertinent. (Leipsic, 1745.)—(T. H. S.)

Plattenepithel. (G.) Pavement epithelium; and stratified epithelium.

Platycoria. Platycoriasis. Mydriasis.

Platyopthalmon. (L.) A name for antimony trisulphide which, used as a pigment, is supposed to make a beautiful, broad-looking eye.

Platyscopic. Having a wide and flat field of view.

Doyne (*Oph. Year-Book*, p. 94, 1904) has suggested *platyscopic spectacles*, powerful biconvex lenses of crown glass, with two menisci of flint glass fused together and a small electric incandescent lamp attached to the top of the glass or metal disc carrying the same, as an aid to those whose sight is extremely defective. The combination forms, in fact, a miniature microscope.

Pleiochroism. Polychroism. It has long been known that in certain crystals, such as some specimens of topaz, three distinct colors may be

observed on looking through them along three rectangular axes. In intermediate directions intermediate tints may be observed.

Plempius, Vopiscus Fortunatus (1601-1671). Born at Amsterdam, and professor at Louvain, he was at first a bitter opponent of Harvey, but later presented a complete right-about-face, warmly supporting, then, the doctrine of the circulation of the blood. He was a very prolific writer, but none of his works, save one, relates to ophthalmology. The book in question is entitled "*Ophthalmographia, sive Tractatio de Oculi Fabrica*, etc." (Amst., 1632; Louvain, 1648). This book is not especially original, but is memorable nevertheless for being the very first (after 28 years even so) to espouse the revolutionary, and, for the most part, absolutely correct, optical doctrines of Johannes Keppler (q. v.). —(T. H. S.)

Plenck, Joseph Jacob. A celebrated Austrian anatomist, surgeon, obstetrician and ophthalmologist, who gave the first course of lectures on eye-diseases ever delivered in Hungary. Born at Vienna, November 28, 1738, he there received his medical degree and, for a time, was professor, at Basel, of anatomy, surgery and obstetrics. In 1770 he was called to Tyrnau, and almost immediately thereafter to Budapest. In the last named city he added ophthalmology to his list of branches. In 1783 he was called to the chair of chemistry and botany at the Joseph's Academy in Vienna, and soon thereafter held a number of official positions in the service of the Austrian Government. He was ennobled in 1790, and died at Vienna, Aug. 24, 1807.

His writings, though numerous and valuable, possess but little ophthalmologic importance, excepting only the "*Doctrina de Morbis Oculorum*" (Vienna, 1777), pronounced by Hirschberg to be an excellent compendium, "the first . . . which made conveniently accessible to students and physicians the achievements of the ophthalmologic renaissance of the 18th century."—(T. H. S.)

Pleochroic, Pleochromatic. Pleochrous. Characterized by pleochroism.

Pleochroism, Pleochromatism. The quality of certain crystals of exhibiting different colors when viewed in different directions.

Pleochromatism. The property possessed by some crystals of transmitting one color in one position and the complementary color in a position at right angles to the first.

Pleomorphic. Pleomorphous. Assuming various distinct forms, e. g., a pleomorphous bacillus.

Plethysmography. The art of recording modifications in the size or mass of a part by observing changes in its blood circulation. For this purpose Krauss (*Oph. Year-Book*, p. 289, 1909) has examined a large

number of healthy and diseased eyes and other orbital contents by means of an air-tight chamber, the anterior wall of which is transparent. His researches so far undertaken (to the time of the reference named) relate to the physiology and pathology of winking, secretion of the tears, various movements of the globe, venous drainage of the orbit, vasomotor nerve supply of the orbital vessels, etc. A suitable lens inserted in the anterior wall facilitates ophthalmoscopic examination. The same apparatus can be used for the most varied purposes, including the application of therapeutic measures to the eyeball and lids.

Plexiform angiomata. See p. 466, Vol. I, and pp. 9112 and 9120, Vol. XII of this *Encyclopedia.*

Plexiform neuroma. See p. 8361, Vol. XI, also p. 5019, Vol. VII of this *Encyclopedia.*

Plexiform neurofibroma. See, also, **Blepharochalasis,** p. 1037, Vol. II of this *Encyclopedia.*

Plexus annularis. The nerve plexus that encircles the margin of the cornea.

Plexus, Choroid. A vascular, fringe-like fold of the pia in the third, fourth, and lateral ventricles. The choroid plexuses secrete the cerebrospinal fluid.

Plexus, Ciliary. Canal of Schlemm.

Plexus iridis. One of numerous minute folds on the posterior surface of the iris.

Plexus lacrimalis. Huschke's valve.

Plexus, Ophthalmic. A nerve plexus around the ophthalmic artery and the optic nerve.

Plicæ ciliares. The folds of the choroid posterior and corresponding to each of the ciliary processes.

Plica polonica. The name of a disease of the scalp (sometimes extending to the eyebrows and lashes) in which the hairs become matted together by an adhesive and often fetid secretion, and which is especially prevalent in Poland, although it occasionally occurs in other countries. The hair is found, on microscopic investigation, to be infested with a fungus of the genus Trichophyton.

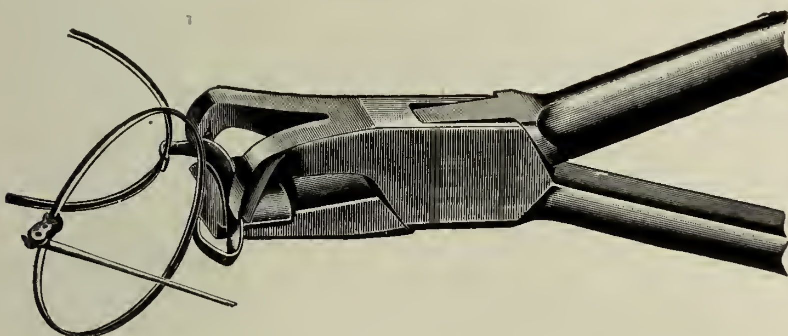
Plica semilunaris. The reduplication at the inner canthus of the conjunctiva forming a well-marked semilunar fold; practically the third eyelid. See **Membrana nictitans,** p. 7363, Vol. X of this *Encyclopedia.*

The plica participates in most of the diseases of the conjunctiva in general. Largely localized inflammations of the caruncle and plica

were formerly known as *encanthis*. See p. 4305, Vol. VI of this *Encyclopedia*.

Pli courbe. (F.) Angular convolution.

Pliers, Ophthalmic. Whether he occupies himself with the mechanical aspects of adjusting glasses or not, every ophthalmologist should have a practical knowledge of the subject. For this reason the cap-



Berg Crest Plier.

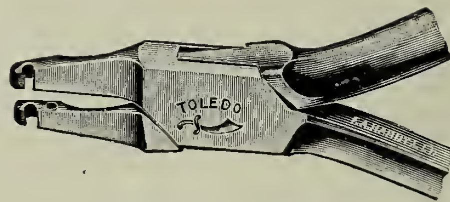
tion, **Eyeglasses and spectacles, Adjustment of,** p. 4953, Vol. VII of this *Encyclopedia*, should not be neglected. The use of pliers is considered on page 4981 and to the instruments there depicted are added here illustrations of several others, intended further to elucidate the text.

The Hardy *shanking plier* is to be used with either frames or spectacle mountings. With this tool one may grasp the shank of a spectacle

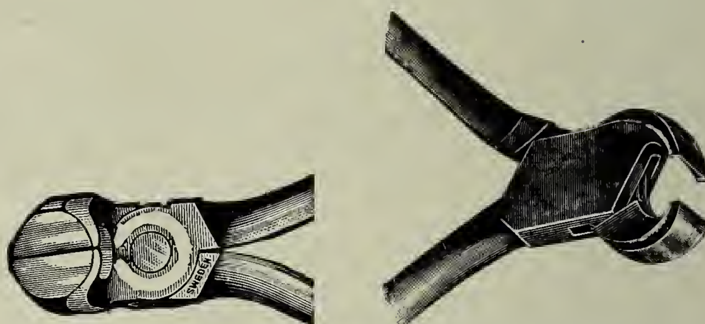
The Hardy Shanking Plier.

bridge at the end where it joins the eye wire or the lens strap and accomplish a neat bend close to the tip.

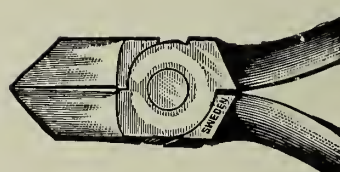
The *adjustable and tilting pliers* that figure in the text is intended to ''position'' the coil spring when attaching to fingerpiece mounting. The ends of the jaws are fashioned for holding the coil spring mounting secure while shaping. With use of the curved faces on the jaws it then becomes a tilting pliers for either crest or end pieces on spectacles.



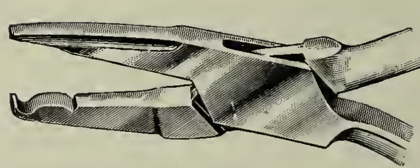
Adjustable and Tilting Pliers.



Sweedish End Cutting Pliers.



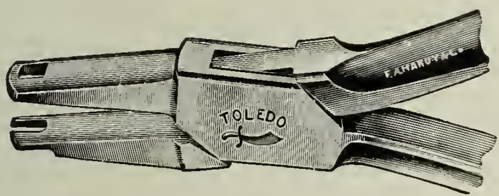
Sweedish Side Cutting Pliers.



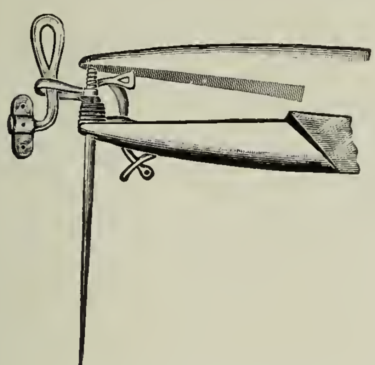
Special Pliers for Adjusting the Bridge of Spectacles.

The (illustrated) combination "hollow chop" spectacle pliers is also an assembling pliers for regular offset guard eye glass mounting.

By the use of the so-called "third hand" pliers a coil spring can be fitted to a fingerpiece mounting as easily as a screw can be fitted to a riding bow frame and the bridge on the same style mounting can be bent and the glasses aligned with ease.



Hollow Chop Spectacle and Eye Glass Plier.



The Third Hand Plier.

Pliny, Caius Plinius Secundus, called "the Elder" by way of distinction from his nephew of the same name. An ancient Roman military officer, imperial governor, and (by far the most important matter for our purposes) encyclopedic scholar. Born at Novum Comum (Como) in Upper Italy, A. D. 23, he was for the most of his life engaged in military or administrative duties. Thus, under Claudius, he was *prefectus alæ* (a commander of horse) in Germany; under Vespasian, imperial governor in several provinces; and, under Titus, commander of the fleet at Misenum. He died, A. D. 79, in the eruption of Vesuvius which destroyed Herculaneum and Pompeii. The account of his death is given with much detail by his nephew, the Younger Pliny, in Book VI, Letter 16, of his *"Epistles."*

In addition to works on war, biography, grammar, history and rhetoric (not one of which has come down to our day) he wrote the famous *Historia Naturalis,* or "Natural History," which has been preserved entire. This monumental work is indeed the greatest treasury of ancient Greco-Roman knowledge that we now possess. Compiled from about 2,000 writings of 474 authors, it deals, in the following order, with astronomy, physics, geography, ethnography, anthropology, zoology, botany, mineralogy, pharmacology, medicine, painting, sculpture, the engraving of gems and comparative geography. The enormous work was planned, executed and revised in the space of two years—77-78 A. D. As a result, in part at least, of the haste with which the book was put together, it contains (in spite of its very great value) a large number of mistakes. Then, too, Pliny was, as it seems, by nature a very careless writer, and, in addition, a man devoid of critical acumen and deeply tinctured with superstition.

It is chiefly, of course, the medical portions of the great book of Pliny that are of interest to physicians. Pliny, however, we may say at the outset, was not favorable to doctors, as the following extracts from his writings abundantly prove: "And there is no doubt that they all busy themselves with our lives, in order by the discovery of some new thing or another to win reputation for themselves. Hence flow those pitiable disputes over the sick; for no one has the same views as another; hence also that inscription upon the tombstone of the unfortunate victim: 'He died by reason of the confusion of the doctors.' This spurious art is changed so often and so lamentably, and we are driven to and fro by the breath of the spirits of Greece." Again: "There is, alas, no law against incompetency, no striking example is made. They learn by our bodily jeopardy, and make experiments until the death of the patients. And the doctor is the only person not punished for murder."

In spite, however, of Pliny's all too plainly expressed disgust and contempt for medicine and doctors, his observations on matters connected with the eye are of interest to the modern ophthalmologist—some of them for one reason and some for another. Following are all the passages which I have been able to find in the *Historia Naturalis* which bear upon the eye, and these I give in the order in which they occur in the book. The translation is almost always that of Bostock and Riley, but, in a number of instances, I have ventured my own translation. My comment I have given in the form of footnotes.

BOOK II, CHAP. 41.—OF THE REGULAR INFLUENCE OF THE DIFFERENT SEASONS.

. . . certain accurate observers have found out, that the entrails of the field-mouse correspond in number to the moon's age, and that the very small animal, the ant, feels the power of this luminary, for she always refrains from her labors at the changing of the moon.* And so much the more disgraceful is our ignorance, as everyone acknowledges that the diseases in the eyes of certain beasts of burden increase and diminish according to the age of the moon. . . .

BOOK VII, CHAP. 2.—THE WONDERFUL FORMS OF DIFFERENT NATIONS.

. . . .

In the vicinity also of those who dwell in the northern regions, and not far from the spot from which the north wind arises, and the place which is called its cave, and is known by the name of Geskleithron, the Arimaspi are said to exist, whom I have previously mentioned, a nation remarkable for having but one eye, and that placed in the middle of the forehead. This race is said to carry on a perpetual warfare with the Griffins, a kind of monster, with wings, as they are commonly represented, for the gold which they dig out of the mines, and which these wild beasts retain and keep watch over with a singular degree of cupidity, while the Arimaspi are equally desirous to get possession of it . . .

. . . The same author relates, that there is, in Albania, a certain race of men, whose eyes are of a sea-green color, and who have white hair from their earliest childhood, and that these people see better in the night than in the day. . . .

. . . Isigonus adds, that there are among the Triballi and the Illyrii, some persons of this description, who also have the power of fascination with the eyes, and can even kill those on whom they fix their gaze for any length of time, more especially if their look denotes anger; the age of puberty is said to be particularly obnoxious to the malign influence of such persons.†

A still more remarkable circumstance is the fact that these persons

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* I have now and then extracted a tiny bit more than merely the sentences which speak about the eye, in order that the clearness of such sentences may be preserved.

† See, in this *Encyclopedia*, for comparative purposes, the articles entitled "**Basilisk**," "**Cockatrice**," and "**Catoblephas**;" also, in this present article, Book VIII, Chaps. 32 and 33.

have two pupils in each eye. Apollonides says, that there are certain females of this description in Scythia, who are known as Bythiæ, and Phylarchus states that a tribe of the Thibii in Pontus, and many other persons as well, have a double pupil in one eye, and in the other the figure of a horse.‡ He also remarks, that the bodies of these persons will not sink in water, even though weighed down by their garments. Damon gives an account of a race of people, not very much unlike them, the Pharnaces of Æthiopia, whose perspiration is productive of consumption to the body of every person that it touches. Cicero also, one of our own writers, makes the remark that the glances of all women who have a double pupil is noxious.

To this extent, then, has nature, when she produced in man, in common with the wild beasts, a taste for human flesh, thought fit to produce poisons as well in every part of his body, and even in the eyes of some persons, taking care that there should be no evil influence in existence, which was not to be found in the human body. Not far from the city of Rome, in the territory of the Falisci, a few families are found, who are known by the name of Hirpi. These * people perform a yearly sacrifice to Apollo, on Mount Soracte, on which occasion they walk over a burning pile of wood, without so much as being scorched. On this account, by virtue of a decree of the senate, they are always exempted from military service, and from all other public duties.

Certain persons, again, are born with certain parts of the body endowed with properties of a marvelous nature. Such was the case with King Pyrrhus, the great toe of whose right foot cured diseases of the spleen, if it merely touched the patient. We are also informed that this toe could not be reduced to ashes together with the other portions of his body; upon which it was placed in a coffer, and preserved in a temple.

India, and the region of Ethiopia more especially, abounds in wonders. In India the largest of animals are produced; their dogs, for example, are much bigger than those of any other country. . . . It is a well known fact, that many of the people here are

‡ Bostock has the following footnote: "Some of the commentators have supposed, that Pliny, or Phylarchus, from whom he borrows, was misled by the ambiguity of the Greek term Hippos, which signifies either a horse, or a tremulous motion of the eye. But, even admitting this to be the case, the wonder is scarcely diminished; for we have the double pupil of one eye, while this supposed tremulous motion is confined to the other."

* Once again I have quoted matter which does not bear directly on the eye. It seemed to me, however, that the general spirit of the chapters in question could not quite be understood without at least a little of this (otherwise) irrelevant matter.

more than five cubits in height. These people never expectorate, are subject to no pains, either in the head, the teeth, or the eyes, and rarely in any other parts of the body; so well is the heat of the sun calculated to strengthen the constitution. Their philosophers, who are called Gymnosophists, remain in one posture, with their eyes immovably fixed upon the sun, from its rising to its setting, and, during the whole of the day, they are accustomed to stand in the burning sands, first on one foot then upon the other. . . .

On many of the mountains again, there is a tribe of men who have the heads of dogs, and clothe themselves with the skins of wild beasts. . . . The same people are also called Sciapodæ, because they are in the habit of lying on their backs, during the hottest portion of the day, and then protecting themselves from the sun by the shade of their feet. These people, he says, dwell not very far from the Troglodytæ; to the west of whom again there is a tribe who are without necks, and have eyes in their shoulders.

Among the mountainous districts of the eastern parts of India, in what is called the country of the Catharcludi, we find the Satyr, an animal of extraordinary swiftness. . . . A nation which dwell in the woods and have no proper voice is called by Tauron "Choromandæ." These people screech in a frightful manner; their bodies are covered with hair, their eyes are of a sea-green color, and their teeth like those of the dog. . . .

BOOK VII, CHAP. 21.—INSTANCES OF ACUTENESS OF SIGHT.

Instances of acuteness of sight are to be found stated, which, indeed, exceed all belief. Cicero informs us, that the Iliad of Homer was written on a piece of parchment so small as to be enclosed in a nutshell. He likewise mentions a man who could distinguish objects at a distance of one hundred and thirty-five miles.† M. Varro says, that the name of this man was Strabo; and that, during the Punic war, from Lilybæum, the promontory of Sicily, he was in the habit of seeing the fleet come out of the harbor of Carthage, and could even count the number of the vessels. Callicrates used to carve in ivory ants and other small animals, so minute that other persons were unable to distinguish their individual parts. Myrmecides also was famous in the same line; this man produced, of similar material, a chariot drawn by four horses, which a fly could cover with its wings; as well as a ship which might be covered by the wings of a tiny bee.

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† For the true limitations of the power of human vision, see *supra*, **Legal relations of ophthalmology.**

BOOK VIII, CHAP. 32.—THE ANIMALS OF ÆTHIOPIA; A WILD BEAST WHICH KILLS WITH ITS EYE.

Among the Hesperian Æthiopians is the Fountain of Nigris, by many supposed to be the head of the Nile. I have already mentioned the arguments by which this opinion is supported. Near this fountain there is found a wild beast, which is called the catoblepas; ‡ an animal of moderate size, and sluggish in the movements of its limbs; its head is remarkably heavy, and is only carried with the greatest difficulty, being always bent down towards the earth. But for this circumstance, it would prove the destruction of the human race; for all who behold its eyes, fall dead upon the spot.

CHAP. 33.—THE SERPENTS CALLED BASILISKS.

There is the same power also in the serpent called the basilisk. It is produced in the province of Cyrene, being not more than twelve fingers in length. It has a white spot on the head, strongly resembling a sort of diadem. When it hisses, all other serpents fly from it: and it does not advance its body, like the others, by a succession of folds, but moves along upright and erect upon the middle. It destroys all shrubs, not only by its contact, but those even that it has breathed upon; it burns up all the grass too, and breaks the stones, so tremendous is its noxious influence. It was formerly a general belief that if a man on horseback killed one of these animals with a spear, the poison would run up the weapon and kill, not only the rider, but the horse as well. To this dreadful monster the effluvium of the weasel is fatal, a thing that has been tried with success, for kings have often desired to see its body when killed; so true is it that it has pleased Nature that there should be nothing without its antidote. The animal is thrown into the hole of the basilisk, which is easily known from the soil around it being infected. The weasel destroys the basilisk by its odor, but dies itself in this struggle of nature against its own self.

CHAP. 34.—WOLVES; THE ORIGIN OF THE STORY OF VERSIPELLIS.

In Italy, also, it is believed that there is a noxious influence in the eye of a wolf; it is in fact supposed that the wolf will instantly take away the voice of a man, if it is the first to see him. . . .

‡ Written also "catoblephas" and "catoblefas."

CHAP. 45.—THE COROCOTTA; THE MANTICHORA.

By the union of the hyæna with the Æthiopian lyoness, the corocotta is produced, which has the same faculty of imitating the voices of men and cattle. Its gaze is always fixed and immovable; it has no gums in either of its jaws, and the teeth are one continuous piece of bone. . . .

CHAP. 51.—THE CHAMELEON.

Africa is almost the only country that does not produce the stag, but then it produces the chameleon, an animal much more commonly met with in India. Its figure and size are those of a lizard, only its legs are straight and longer. . . . It has hooked claws, and a slow movement like that of the tortoise; its body is rough like that of the crocodile; its eyes are deep sunk in the orbits, placed very near each other, very large, and of the same color as the body. It never closes them, and when the animal looks round, it does so, not by the motion of the pupil, but of the white of the eye. . . . The nature of its color, too, is very remarkable, for it is continually changing; its eyes, its tail, and its whole body always assuming the color of whatever object is nearest, with the exception of white and red. . . . It has no blood whatever, except in the heart and about the eyes, and its entrails are without a spleen. . . .

BOOK XI, CHAP. 51.—THE FACE, THE FOREHEAD, AND THE EYE-BROWS.

Man is the only creature that has a face, the other animals having only a muzzle or a beak. Other animals have a forehead as well, but it is only on the forehead of man that is depicted sorrow, gladness, compassion, or severity. It is the forehead that is the index of the mind. Man has eye-brows, also, which move together or alternately; these, too, serve in some measure as indications of the feelings. Do we deny or do we assent, it is the eye-brows, mostly, that indicate our intentions. Feelings of pride may be generated elsewhere, but it is here that they have their principal abode; it is in the heart that they take their rise, but it is to the eye-brows that they mount, and here they take up their position. In no part of the body could they meet with a spot more lofty and more precipitous, in which to establish themselves free from all control.

CHAP. 52.—THE EYES—ANIMALS WHICH HAVE NO EYES, OR HAVE ONLY ONE EYE.

Below the forehead are the eyes, which form the most precious portion of the human body, and which, by the enjoyment of the blessings of sight, distinguish life from death. Eyes, however, have not been granted to all animals; oysters have none, but, with reference to some of the shell-fish, the question is still doubtful; for if we move the fingers before a scallop half open, it will immediately close its shell, apparently from seeing them, while the solen will start away from an iron instrument when placed near it. Among quadrupeds the mole has no sight,* though it has something that bears a resemblance to eyes, if we remove the membrane that is extended in front of them. Among birds also, it is said that a species of heron, which is known as the "leucus," is wanting of one eye: a bird of most excellent augury, when it flies towards the south or north, for it is said that it portends thereby that there is about to be an end of perils and alarms. Nigidius says also, that neither locusts nor grasshoppers have eyes. In snails,† the two small horns with which they feel their way, perform the duties of eyes. Neither the lumbricus nor any other kind of worm has eyes.

CHAP. 53.—THE DIVERSITY OF THE COLOR OF THE EYES.

The eyes vary in color in the human race only; in all other animals they are of one uniform color peculiar to the kind, though there are some horses that have eyes of an azure color. But in man the varieties and diversities are most numerous; the eyes being either large, of middling size, remarkably small, or remarkably prominent. These last are generally supposed to be very weak, while those that are deep-seated are considered the best, as is the case also with those which in color resemble the eyes of the goat.

CHAP. 54.—THE THEORY OF SIGHT—PERSONS WHO CAN SEE BY NIGHT.

In addition to this, there are some persons who can see to a very great distance, while there are others, again, who can only distinguish

* So also Artistotle, but not Galen.

† How poor an observer Pliny was, is plainly shown by this remark about the eyelessness of snails, grasshoppers and locusts.

objects when brought quite close to them. The vision of many stands in need of the rays of the sun; such persons cannot see on a cloudy day, nor yet after the sun has set. Others, again, have bad sight in the day-time, but a sight superior to that of others by night. Of persons having double pupils, or the evil eye, we have already spoken at sufficient length. Blue eyes are the best for seeing in the dark.

It is said that Tiberius Cæsar, like no other human being, was so endowed by Nature that on awaking in the night he could for a few moments distinguish objects just as well as in the clearest daylight, but that by degrees he would find his sight again enveloped in darkness. The late Emperor Augustus had azure eyes like those of some horses, the white being larger than with other men; he used to be very angry if a person stared intently at them for this peculiarity. Claudius Cæsar had at the corners of the eyes a white fleshy substance, covered with veins, which would occasionally become suffused with blood; with the Emperor Caius they had a fixed, steady gaze, while Nero could see nothing distinctly without winking, and having it brought close to his eyes. The Emperor Caius had twenty pairs of gladiators in his training-school, and of all these there were only two who did not wink the eyes when a menacing gesture was made close to them; hence it was that these men were invincible. So difficult a matter is it for a man to keep his eyes from winking: indeed, to wink is so natural to many that they cannot desist from it; such persons we generally look upon as the most timid.

No persons have the eye all of one color; that of the middle of the eye is always different from the white which surrounds it. In all animals there is no part in the whole body that is a stronger exponent of the feelings, and in man more especially, for it is from the expression of the eye that we detect clemency, moderation, compassion, hatred, love, sadness, and joy. From the eyes, too, the various characters of persons are judged of, according as they are ferocious, menacing, sparkling, sedate, leering, askance, downcast, or languishing. Beyond a doubt it is in the eyes that the mind has its abode: sometimes the look is ardent, sometimes fixed and steady, at other times the eyes are humid, and at others, again, half closed. From these it is that the tears of pity flow, and when we kiss them we seem to be touching the very soul. It is the eyes that weep, and from them proceed those streams that moisten our cheeks as they trickle down.* And what is this liquid that is always so ready and in such abundance

* This profound remark reminds us of that of a certain public speaker: "A lamb, my friends, is a defenceless animal."

in our moments of grief, and where is it kept in reserve at other times? † It is by the aid of the mind that we see, by the aid of the mind that we enjoy perception; while the eyes, like so many vessels, as it were, receive its visual faculties and transmit them. Hence it is that profound thought renders a man blind for the time, the powers of sight being withdrawn from external objects and thrown inward: so, too, in epilepsy, the mind is covered with darkness, while the eyes, though open, are able to see nothing. In addition to this, it is the fact that hares, as well as many human beings, can sleep with the eyes open, a thing that the Greeks express by the term korubantian. Nature has composed the eye of numerous membranes of remarkable thinness, covering them with a thick coat to ensure their protection against heat and cold. This coat she purifies from time to time by the lachrymal humors, and she has made the surface lubricous and slippery, to protect the eye against the effects of a sudden shock.

CHAP. 55.—THE NATURE OF THE PUPIL—EYES WHICH DO NOT SHUT.

In the midst of the cornea of the eye Nature has formed a window in the pupil, the small dimensions of which do not permit the sight to wander at hazard and with uncertainty, but direct it as straight as though it were through a tube, and at the same time ensure its avoidance of all shocks communicated by foreign bodies. The pupils are surrounded by a black circle in some persons, while it is of a yellowish cast with others, and azure again with others. By this happy combination the light is received by the eye upon the white that lies around the pupil, and its reflection being thus tempered, it fails to impede or confuse the sight by its harshness. So complete a mirror, too, does the eye form, that the pupil, small as it is, is able to reflect the entire image of a man.‡ This is the reason why most birds, when held in the hand of a person, will more particularly peck at his eyes; for seeing their own likeness reflected in the pupils, they are attracted to it by what seem to be the objects of their natural affection.

It is only some few beasts of burden that are subjects to maladies of the eyes towards the increase of the moon: but it is man alone that is

† Even the much more scientific Galen (d. 201 or 210 A. D.) had no clear notion of the origin of tears. The lachrymal glands may in fact be said to have been discovered by Stenson (*alias* Steno, 1638-1686) in 1661. (To the contrary, Hirschberg, "*Gesch. d. Augenh.*," ALTERTHUM, p. 201.) Steno was also the first to prove that the heart is a muscle, and he likewise discovered Steno's duct.

‡ This image, of course, is formed by the anterior surface of the cornea.

reseued from blindness by the diseharge of the humors that have caused it. Many persons have had their sight restored after being blind for twenty years; while others, again, have been denied this blessing from their very birth, without there being any blemish in the eyes. Many persons, again, have suddenly lost their sight from no apparent cause, and without any preeeding injury. The most learned authors say that there are veins whieh communieate from the eye to the brain, but I am inelined to think that the communieation is with the stomach; for it is quite certain that a person never loses the eye without feeling sickness at the stomach. It is an important and saered duty, of high sanetion among the Romans, to elose the eyes of the dead, and then again to open them when the body is laid on the funeral pile, the usage having taken its rise in the notion of its being improper that the eyes of the dead should be beheld by man, while it is an equally great offense to hide them from the view of heaven. Man is the only living ereature the eyes of whieh are subjeet to deformities, from whieh, in faet, arose the family names of "Strabo" and "Pætus." The ancients used to eall a man who was born with only one eye, "eocles," and "oeella," a person whose eyes were remarkably small. "Luseinus" was the surname given to one who happened to have lost one eye by an aeeident.

The eyes of animals that see at night in the dark, cats, for instance; are shining and radiant, so much so that it is impossible to look upon them; those of the she-goat, too, and the wolf are resplendent, and emit a light-like fire. The eyes of the sea-ealf and the hyena ehange sueeessively to a thousand eolors; and the eyes, when dried, of most of the fishes will give out light in the dark, just in the same way as the trunk of the oak when it has beeome rotten with extreme old age. We have already mentioned the faet that animals whieh turn, not the eyes but the head, for the purpose of looking round, are never known to wink. It is said, too, that the ehameleon is able to roll the eye-balls eompletely round. Crabs look sideways, and have the eyes enelosed beneath a thin erust. Those of eraw-fish and shrimps are very hard and prominent, and lie in a great measure beneath a defense of a similar nature. Those animals, however, the eyes of whieh are hard, have worse sight than those of which the eyes are formed of a humid substance. It is said that if the eyes are taken away from the young of serpents and of the swallow, they will grow again. In all insects and in animals covered with a shell, the eyes move just in the same way as the ears of quadrupeds do; those among them whieh have a brittle eovering have the eyes hard. All animals of this nature, as well as fishes and insects, are destitute of eye-lids, and their eyes have

no covering; but in all there is a membrane that is transparent like glass, spread over them.

CHAP. 56.—THE HAIR OF THE EYE-LIDS; WHAT ANIMALS ARE WITHOUT THEM. ANIMALS WHICH CAN SEE ON ONE SIDE ONLY.

Man has lashes on the eye-lids on either side; and women even make it their daily care to stain them; so ardent are they in the pursuit of beauty, that they must even color their very eyes. It was with another view, however, that Nature had provided the hair of the eye-lids—they were to have acted, so to say, as a kind of rampart for the protection of the sight, and as an advanced bulwark against the approach of insects or other objects which might accidentally come in their way. It is not without some reason that it is said that the eye-lashes fall off with those persons who are too much given to venereal pleasures.* Of the other animals, the only ones that have eye-lashes are those that have hair on the rest of the body as well; but the quadrupeds have them on the upper eyelid only, and the birds on the lower one: the same is the case also with those which have a soft skin, such as the serpent, and those among the quadrupeds that are oviparous, the lizard, for instance. The ostrich is the only one among the birds that, like man, has eyelashes on either side.

CHAP. 57.—ANIMALS WHICH HAVE NO EYELIDS.

Not all birds, however, have eyelids: hence it is that those which are viviparous have no nictation of the eye. The heavier kinds of birds shut the eye by means of the lower eyelid, and they wink by drawing forward a membrane which lies in the corner of the eye. Pigeons, and other birds of a similar nature, shut the two eyelids; but the quadrupeds which are oviparous, such, for instance, as the tortoise and the crocodile, have only the lower eyelid moveable, and never wink, in consequence of the hardness of the eye. The edge of the upper eyelid was by the ancients called "cilium," from which comes our word "supercilia." If the eyelid happens to be severed by a wound it will not reunite,† which is the case also with some few other parts of the human body.

* Possibly an allusion to syphilitic madarosis; though, of course, all who believe in the American origin of syphilis would not admit this. It is interesting to know that Pliny himself had an ulcer of the penis, which he thought unhealable, and which was probably a chancre.

† A great mistake, of course.

BOOK XX, CHAP. 20.—ONIONS: TWENTY-SEVEN REMEDIES.

There are no such things in existence as wild onions. The cultivated onion is employed for the cure of dimness of sight, the patient being made to smell at it till tears come into the eyes: it is still better even if the eyes are rubbed with the juice. . . . Applied, too, in the same way, they are good for healing excoriations. Roasted in hot ashes, many persons have applied them topically, with barley meal, for defluxions of the eyes and ulcerations of the genitals. The juice, too, is employed as an ointment for sores of the eyes, albugo, and argema.

BOOK XXV, CHAP. 50.—PLANTS WHICH HAVE BEEN DISCOVERED BY CERTAIN ANIMALS. CHELIDONIA: SIX REMEDIES.‡

The brute animals also have been the discoverers of certain plants: among them, we will name chelidonia first of all. It is by the aid of this plant that the swallow restores the sight of the young birds in the nest, and even, as some persons will have it, when the eyes have been plucked out. There are two varieties of this plant; the larger kind has a branchy stem, and a leaf somewhat similar to that of the wild parsnip, but larger. The plant itself is some two cubits in height, and of a whitish color, that of the flower being yellow. The smaller kind has leaves that are like that of ivy, only rounder and not so white. The juice of it is pungent, and resembles saffron in color, and the seed is similar to that of the poppy.

These plants blossom, both of them, at the arrival of the swallow, and wither at the time of its departure. The juice is extracted while they are in flower, and is boiled gently in a copper vessel on hot ashes, with attic honey, being esteemed a sovereign remedy for films upon the eyes. This juice is employed also, unmixed with any other substance, for the eyesalves, which from it take their name of "chelidonia."

CHAP. 91.—REMEDIES FOR DISEASES OF THE EYES.

It is generally thought that the greater centaury strengthens the sight, if the eyes are fomented with it steeped in water; and that by employing the juice of the smaller kind, in combination with honey, films and cloudiness may be dispersed, marks obliterated, and small

‡ Chelidonia as an ophthalmic medicine enjoyed so high a reputation among the ancients that Pliny's famous passage is here reproduced *in extenso*.

flies removed which have got into the eye. It is thought also that sideritis is curative of albugo in beasts of burden. As to chelidonia, it is marvelously good for all the affections above mentioned. Root of panaces is applied, with polenta, to defluctions of the eyes; and for the purpose of keeping them down, henbane-seed is taken, in doses of one obolus, with an equal proportion of opium, in wine. Juice, too, of gentian is used as a liniment, and it sometimes forms an ingredient in the more active eyesalves, as a substitute for meconium. Euphorbia, applied in the form of a liniment, improves the eyesight, and for ophthalmia juice of plantago is injected into the eyes.

Aristolochia disperses films upon the eyes; and iberis, attached to the head with cinquefoil, is curative of defluxions and other diseases of the eyes. Verbascum is applied topically to defluxions of the eyes, and vervain is used for a similar purpose, with rose oil and vinegar. For the treatment of cataract and dimness of sight, cyclaminos is reduced to a pulp and divided into lozenges. Juice, too, of peucedanum, as already mentioned, mixed with meconium and oil of roses, is good for the sight, and disperses films upon the eyes. Psyllion, applied to the forehead, arrests defluxions of the eyes.

CHAP. 92.—THE ANAGALLIS, OR CORCHORON; TWO VARIETIES OF IT: SIX REMEDIES.

The anagallis is called "corchoron" by some. There are two kinds of it, the male plant, with a red blossom, and the female, with a blue flower. These plants do not exceed a palm in height, and have a tender stem, with diminutive leaves of a rounded form, drooping upon the ground. They grow in gardens and in spots covered with water, the blue anagallis being the first to blossom. The juice of either plant, applied with honey, disperses films upon the eyes, suffusions of blood in those organs resulting from blows, and argema with a red tinge: if used in combination with attic honey, they are still more efficacious. The anagallis has the effect also of dilating the pupil; hence the eye is anointed with it before the operation of couching for cataract. These plants are employed also for diseases of the eyes in beasts of burden.

The juice, injected into the nostrils, which are then rinsed with wine, acts as a detergent upon the head: it is taken also, in doses of one drachma, in wine, for wounds inflicted by serpents. It is a remarkable fact, that cattle will refuse to touch the female plant; but if it should happen that, deceived by the resemblance—the flower being the only distinguishing mark—they have accidentally tasted it, they immediately

have recourse, as a remedy, to the plant called "asyla," but more generally known among us as "ferus oculus." * Some persons recommend those who gather it, to prelude by saluting it before sunrise, and then, before uttering another word, to take care and extract the juice immediately; if this is done, they say, it will be doubly efficacious.

As to the juice of euphorbia, we have spoken of its properties at sufficient length already. In cases of ophthalmia, attended with swelling, it will be a good plan to apply worm-wood beaten up with honey, as well as powdered betony.

CHAP. 93.—THE ÆGILOPS: TWO REMEDIES.

The fistula of the eye, called "ægilops," is cured by the agency of the plant of the same name, which grows among barley, and has a leaf like that of wheat. The seed is pounded for the purpose, and applied with meal; or else the juice is extracted from the stem and more pulpy leaves, the ears being first removed. This juice is incorporated with meal of three-month wheat, and divided into lozenges.

CHAP. 94.—MANDRAGORA, CIRCÆON, MORION, OR HIPPOPHLOMOS; TWO VARIETIES OF IT: TWENTY-FOUR REMEDIES.

Some persons, too, were in the habit of employing mandragora for diseases of the eyes; but more recently, the use of it for such a purpose has been abandoned. It is a well-ascertained fact, however, that the root, beaten up with rose oil and wine, is curative of defluxions of the eyes and pains in those organs; and, indeed, the juice of this plant still forms an ingredient in many medicaments for the eyes. Some persons give it the name of "circæon." There are two varieties, the white mandragora, which is generally thought to be the male plant, and the black, which is considered to be the female. It has a leaf narrower than that of the lettuce, a hairy stem, and a double or triple root, black without and white within, soft and fleshy, and nearly a cubit in length.

Both kinds bear a fruit about the size of a hazel-nut, enclosing a seed resembling the pips of a pear in appearance. The name given to the white plant by some persons is "arsen," by others "morion," and by others again, "hippophlomos." The leaves of it are white, while those of the other one are broader, and similar to those of garden lapathum in appearance. Persons, when about to gather this plant, take every precaution not to have the wind blowing in their face; and,

* "Fierce eye."

after tracing three circles round it with a sword, turn towards the west and dig it up. The juice is extracted both from the fruit and from the stalk, the top being first removed; also from the root, which is punctured for the purpose, or else a decoction is made of it. The filaments, too, of the root are made use of, and it is sometimes cut up into segments and kept in wine.

It is not the mandragora of every country that will yield a juice, but where it does, it is about vintage time that it is collected: it has in all cases a powerful odor, that of the root and fruit the most so. The fruit is gathered when ripe, and dried in the shade; and the juice, when extracted, is left to thicken in the sun. The same is the case, too, with the juice of the root, which is extracted either by pounding it or by boiling it down to one third in red wine. The leaves are best, kept in brine; indeed, when fresh, the juice of them is a baneful poison, and these noxious properties are far from being entirely removed, even when they are preserved in brine. The very odor of them is highly oppressive to the head, although there are countries in which the fruit is eaten. Persons ignorant of its properties are apt to be struck dumb by the odor of this plant when in excess, and too strong a dose of the juice is productive of fatal effects.

Administered in doses proportioned to the strength of the patient, this juice has a narcotic effect; a middling dose being one cyathus. It is given, too, for injuries inflicted by serpents, and before incisions or punctures are made in the body, in order to ensure insensibility to the pain.* Indeed, for this last purpose, with some persons, the odor of it is quite sufficient to induce sleep. The juice is taken also as a substitute for hellebore, in doses of two oboli, in honeyed wine: hellebore, however, is more efficacious as an emetic, and as an evacuant of black bile.

CHAP. 95.—HEMLOCK: THIRTEEN REMEDIES.

Hemlock, too, is a poisonous plant, rendered odious by the use made of it by the Athenian people, as an instrument of capital punishment: still, however, as it is employed for many useful purposes, it must not be omitted. It is the seed that is noxious, the stalk being eaten by many people, either green, or cooked in the saucepan. This stem is smooth, jointed like a reed, of a swarthy hue, often as much as two cubits in height, and branchy at the top. The leaves are like those of coriander, only softer, and possessed of a powerful odor. The seed is

* For a full discussion of the use of mandragora as a surgical anesthetic in ancient Greco-Roman times, as well as the employment of that drug in the same period for various diseases of the eye, see the article, **Mandragora**, in this *Encyclopedia*.

more substantial than that of anise, and the root is hollow and never used. The seed and leaves are possessed of refrigerating properties; indeed, it is owing to these properties that it is so fatal, the cold chills with which it is attended commencing at the extremities. The great remedy for it, provided it has not reached the vitals, is wine, which is naturally of a warming tendency; but if it is taken in wine, it is irremediably fatal.

A juice is extracted from the leaves and flowers; for it is at the time of its blossoming that it is in its full vigor. The seed is crushed, and the juice extracted from it is left to thicken in the sun, and then divided into lozenges. This preparation proves fatal by coagulating the blood—another deadly property which belongs to it; and hence it is that the bodies of those who have been poisoned by it are covered with spots. It is sometimes used in combination with water as a medium for diluting certain medicaments. An emollient poultice is also prepared from this juice, for the purpose of cooling the stomach; but the principal use made of it is as a topical application, to check defluxions of the eyes in summer, and to allay pains in those organs. It is employed also as an ingredient in eyesalves, and is used for arresting fluxes in other parts of the body: the leaves, too, have a soothing effect upon all kinds of pains and tumors, and upon defluxions of the eyes.

CHAP. 96.—CRETHMOS AGRIOS: ONE REMEDY.

Crethmos Agrios,† applied to the eyes, removes rheum; and, with the addition of polenta, it causes tumors to disappear.

CHAP. 97.—MOLYBDÆNA: ONE REMEDY.

Molybdæna ‡ also grows everywhere in the fields, a plant commonly known as "plumbago." It has leaves like those of lapathum, and a thick, hairy root. Chewed and applied to the eye from time to time, it removes the disease called "plumbum," * which affects that organ.

CHAP. 98.—THE FIRST KIND OF CAPNOS, KNOWN ALSO AS CHICKEN'S FOOT: ONE REMEDY.

The first kind of capnos,** known also as "chicken's foot," is found growing on walls and hedges: it has very thin, straggling branches,

† Small samphire, or sea fennel.

‡ Leadwort.

* This has been conjectured to mean some affection characterized by "livid spots on the eyelids."

**Smoke-plant.

with a purple blossom. It is used in a green state, and the juice of it disperses films upon the eyes; it is therefore employed as an ingredient in medicinal compositions for the eyes.

CHAP. 99.—THE ARBORESCENT CAPNOS: THREE REMEDIES.

There is another kind of capnos ‡ also, similar both in name and properties, but different in appearance. It is a branchy plant, is extremely delicate, has leaves like those of coriander, is of an ashy color, and bears a purple flower: it grows in gardens, and amid crops of barley. Employed in the form of an ointment for the eyes, it improves the sight, producing tears in the same way that smoke does, to which, in fact, it owes its name. It has the effect also of preventing the eyelashes, when pulled out, from growing again.

CHAP. 100.—THE ACORON OR AGRION: FOURTEEN REMEDIES.

The acoron § has leaves similar to those of the iris, only narrower, and with a longer stalk; the roots of it are black, and not so veined, but in other respects are similar to those of the iris, have an acrid taste and a not unpleasant smell, and act as a carminative. The best roots are those grown in Pontus, the next best those of Galatia, and the next those of Crete; but it is in Colchis, on the banks of the river Phasis, and in various other watery localities, that they are found in the greatest abundance. When fresh, they have a more powerful odor than when kept for some time: those of Crete are more blanched than the produce of Pontus. They are cut into pieces about a finger in length, and dried in leather bags in the shade.

There are some authors who give the name of "acoron" to the root of the oxymyrsine; for which reason also some prefer giving that plant the name of "acorion." It has powerful properties as a calorific and resolvent, and is taken in drink for cataract and films upon the eyes; the juice also is extracted, and taken for injuries inflicted by serpents.

CHAP. 101.—THE COTYLEDON: TWO VARIETIES OF IT: SIXTY-ONE REMEDIES.

The cotyledon [1] is a small herbaceous plant, with a diminutive, tender stem, and an unctuous leaf, with a concave surface like that

‡ Earth-smoke.
§ Sweet-smelling flag.
[1] Navel-wort.

of the cotyloïd cavity of the thigh. It grows in maritime and rocky localities, is of a green color, and has a rounded root like an olive: the juice of it is remedial for diseases of the eyes.

There is another kind also of the same plant, the leaves of which are of a dirty-green color, larger than those of the other, and growing in greater numbers about the root, which is surrounded with them just as the eye is with the socket. These leaves have a remarkably astringent taste, and the stem is of considerable length, but extremely slender. This plant is employed for the same purposes as the iris and aizoüm.

CHAP. 102.—THE GREATER AIZOUM, ALSO CALLED BUPHTHALMOS, ZOOPHTHALMOS, STERGETHRON, HYPOGESON, AMBROSION, AMERIMNON, SEDUM MAGNUM, OR DIGITELLUS: THIRTY-SIX REMEDIES. THE SMALLER AIZOUM, ALSO CALLED ERITHALES, TRITHALES, CHRYSOTHALES, ISOETES OR SEDUM: THIRTY-TWO REMEDIES.

Of the plant known as aizoüm [2] there are two kinds; the larger of which is sown in earthen pots. By some persons it is known as "buphthalmos," and by others as "zoöphthalmos," or else as "stergethron," because it forms an ingredient in the composition of philtres. Another name given to it is "hypogeson," from the circumstance that it generally grows upon the eaves [3] of houses: some persons, again, give it the names of "ambrosion" and "amerimnon." In Italy it is known as "sedum magnum," "oculus," or "digitellus." The other kind of aizoüm is more diminutive, and is known by some persons as "erithales" and by others as "trithales," from the circumstance that it blossoms three times in the year. Other names given to it are "chrysothales" [4] and "isoëtes:" [5] but aizoüm is the common appellation of them both, from their being always green.

The larger kind exceeds a cubit in height, and is somewhat thicker than the thumb: at the extremity, the leaves are similar to a tongue in shape, and are fleshy, unctuous, full of juice, and about as broad as a person's thumb. Some are bent downwards towards the ground, while others again stand upright, the outline of them resembling an eye in shape. The smaller kind grows upon walls, old rubbish of houses, and tiled roofs; it is branchy from the root, and covered with leaves to the

[2] "Always living."
[3] In Greek, "geisa."
[4] Blossoming like gold.
[5] The same all the year.

extremity. These leaves are narrow, pointed, and juicy: the stem is a palm in height, and the root is never used.

CHAP. 103.—THE ANDRACHLE AGRIA OR ILLECEBRA: THIRTY-TWO REMEDIES.

A similar plant is that known to the Greeks by the name of "andrachle agria,"[6] and by the people of Italy as the "illecebra." Its leaves, though small, are larger than those of the last-named plant, but growing on a shorter stem. It grows in craggy localities, and is gathered for use as food. All these plants have the same properties, being cooling and astringent. The leaves, applied topically, or the juice, in form of a liniment, are curative of defluxions of the eyes: this juice too acts as a detergent upon ulcers of the eyes, makes new flesh, and causes them to cicatrize; it cleanses the eyelids also of viscous matter. Applied to the temples, both the leaves and the juice of these plants are remedial for head-ache; they neutralize the venom also of the phalangium; and the greater aizoüm, in particular, is an antidote to aconite. It is asserted, too, that those who carry this last plant about them will never be stung by the scorpion.

BOOK XXVIII. CHAP. 47.—REMEDIES FOR AFFECTIONS OF THE EYES.

For defluxions of the eyes, beef suet, boiled with oil, is applied to the parts affected; and for eruptions of those organs, ashes of burnt deer's horns are similarly employed, the tips of the horns being considered the most effectual for the purpose. For the cure of cataract, it is reckoned a good plan to apply a wolf's excrements: the same substance, too, reduced to ashes, is used for the dispersion of films, in combination with attic honey. Bear's gall, too, is similarly employed; and for the cure of epinyctis, wild boar's lard, mixed with oil of roses, is thought to be very useful. An ass's hoof, reduced to ashes and applied with asses' milk, is used for the removal of marks in the eyes and indurations of the crystalline humors. Beef marrow, from the right fore leg, beaten up with soot, is employed for affections of the eyebrows, and for diseases of the eyelids and corners of the eyes. For the same purpose, also, a sort of calliblepharon is prepared from soot, the best of all that being made from a wick of papyrus mixed with oil of sesame; the soot being removed with a feather and caught in a new vessel pre-

[6] Wild andrachle, or wild purslane.

pared for the purpose. This mixture, too, is very efficacious for preventing superfluous eyelashes from growing again when once pulled out.

Bull's gall is made up into eye-salves with white of egg, these salves being steeped in water and applied to the eyes for four days successively. Veal suet, with goose-grease and the extracted juice of ocimum, is remarkably good for diseases of the eye-lids. Veal marrow, with the addition of an equal proportion of wax and oil or oil of roses, an egg being added to the mixture, is used as a liniment for indurations of the eye-lids. Soft goats' milk cheese is used as an application, with warm water, to ally defluxions of the eyes; but when they are attended with swelling, honey is used instead of the water. In both cases, however, the eyes should be fomented with warm whey. In cases of dry ophthalmia, it is found a very useful plan to take the muscles lying within a loin of pork, and, after reducing them to ashes, to pound and apply them to the part affected.

She-goats, they say, are never affected with ophthalmia, from the circumstance that they browse upon certain kinds of herbs: the same, too, with the gazelle. Hence it is that we find it recommended, at the time of new moon, to swallow the dung of these animals, coated with wax. As they are able to see, too, by night, it is a general belief that the blood of a he-goat is a cure for those persons affected with dimness of sight to whom the Greeks have given the name of "nyctalopes." * A similar virtue is attributed to the liver of a she-goat, boiled in astringent wine. Some are in the habit of rubbing the eyes with the thick gravy which exudes from a she-goat's liver roasted, or with the gall of that animal: they recommend the flesh also as a diet, and say that the patient should expose his eyes to the fumes of it while boiling: it is a general opinion, too, that the animal should be of a reddish color. Another prescription is, to fumigate the eyes with the steam arising from the liver boiled in an earthen jar, or, according to some authorities, roasted.

Goats' gall is applied for numerous purposes: with honey, for films upon the eyes; with one-third part of white hellebore, for cataract; with wine, for spots upon the eyes, indurations of the cornea, films, webs, and argema; with extracted juice of cabbage, for diseases of the eyelids, the hairs being first pulled out, and the preparation left to dry on the parts affected; and with woman's milk, for rupture of the coats of the eye. For all these purposes, the gall is considered the most efficacious, when dried. Nor is the dung of this animal held

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* See, in this *Encyclopedia,* "**Nyctalopia, History of the term.**"

in disesteem, being applied with honey for defluxions of the eyes. The marrow, too, of a goat, or a hare's lights, we find used for pains in the eyes; and the gall of a goat, with raisin wine or honey, for the dispersion of films upon those organs. It is recommended also, for ophthalmia, to anoint the eyes with wolf's fat or swine's marrow: we find it asserted, too, that persons who carry a wolf's tongue, inserted in a bracelet, will always be exempt from ophthalmia.

BOOK XXIX. CHAP. 37.—REMEDIES FOR AFFECTIONS OF THE EYELIDS.

A crow's brains, taken with the food, they say, will make the eyelashes grow; or else wool-grease, applied with warmed myrrh, by the aid of a fine probe. A similar result is promised by using the following preparation: burnt flies and ashes of mouse-dung are mixed in equal quantities, to the amount of half a denarius in the whole; two-sixths of a denarius of antimony are then added, and the mixture is applied with wool-grease. For the same purpose, also, the young ones of a mouse are beaten up, in old wine, to the consistency of the strengthening preparations known as "acopa." When eyelashes are plucked out that are productive of inconvenience, they are prevented from growing again by using a hedge-hog's gall; the liquid portion, also, of a spotted lizzard's eggs; the ashes of a burnt salamander; the gall of a green lizzard, mixed with white wine, and left to thicken to the consistency of honey in a copper vessel in the sun; the ashes of a swallow's young, mixed with the milky juice of tithymalos; or else the slime of snails.

CHAP. 38.—REMEDIES FOR DISEASES OF THE EYES.

According to what the magicians say, glaucoma † may be cured by using the brains of a puppy seven days old; the probe being inserted in the right side of the eye, if it is the right eye that is being operated on, and in the left side, if it is the left. The fresh gall, too, of the asio is used, a bird belonging to the owlet tribe, with feathers standing erect like ears. Apollonius of Pitanæ used to prefer dog's gall, in combination with honey, to that of the hyena, for the cure of cataract,

† The sense in which the term "glaucoma" was employed by the ancient Greeks and Romans has never been determined satisfactorily. Hippocrates used not "glaucoma," but "glaucosis," and that but a single time. Among both Greeks and Romans, "glaucoma" meant "light blue," and was no doubt applied to what to-day is known as "cataract," as well as to a number of other affections. The notion of hypertension was introduced by Müller and von Graefe.

as also of albugo. The heads and tails of mice, reduced to ashes and applied to the eyes, improve the sight, it is said; a result which is ensured with even greater certainty by using the ashes of a dormouse or wild mouse, or else the brains or gall of an eagle. The ashes and fat of a field-mouse, beaten up with attic honey and antimony, are remarkably useful for watery eyes—what this antimony is, we shall have occasion to say when speaking of metals.

For the cure of cataract, the ashes of a weasel are used, as also the brains of a lizard or swallow. Weasels, boiled and pounded, and so applied to the forehead, allay defluxions of the eyes, either used alone, or else with fine flower or with frankincense. Employed in a similar manner, they are very good for sun-stroke, or in other words, for injuries inflicted by the sun. It is a remarkably good plan, too, to burn these animals alive, and to use their ashes, with Cretan honey, as a liniment for films upon the eyes. The cast-off slough of the asp, with the fat of that reptile, forms an excellent ointment for improving the sight in beasts of burden. To burn a viper alive in a new earthen vessel, with one cyathus of fennel juice, and a single grain of frankincense, and then to anoint the eyes with the mixture, is remarkably good for cataract and films upon the eyes; the preparation being generally known as "echeon." ‡ An eye-salve, too, is prepared, by leaving a viper to putrify in an earthen pot, and bruising the maggots that breed in it with saffron. A viper, too, is burnt in a vessel with salt, and the preparation is applied to the tip of the tongue, to improve the eye-sight, and to act generally as a corrective of the stomach and other parts of the body. This salt is given also to sheep, to preserve them in health, and is used as an ingredient in antidotes to the venom of serpents.

Some persons, again, use vipers as an article of food: when this is done, it is recommended, the moment they are killed, to put some salt in the mouth and let it melt there; after which, the body must be cut away to the length of four fingers at each extremity, and, the intestines being first removed, the remainder boiled in a mixture of water, oil, salt, and dill. When thus prepared, they are either eaten at once, or else kneaded in a loaf, and taken from time to time as wanted. In addition to the above-mentioned properties, viper-broth cleanses all parts of the body of lice, and removes itching sensations as well upon the surface of the skin. The ashes, too, of a viper's head, used by themselves, are evidently productive of considerable effects; they are employed very advantageously in the form of a liniment for

‡ "Viper mixture."

the eyes; and, so, too, is viper's fat. I would not make so bold as to advise what is strongly recommended by some, the use, namely, of vipers' gall; for that, as already stated on a more appropriate occasion, is nothing else but the venom of the serpent. The fat of snakes, mixed with verdigris, heals ruptures of the cuticle of the eyes; and the skin or slough that is cast off in spring, employed as a friction for the eyes, improves the sight. The gall of the boa is highly vaunted for the cure of albugo, cataract, and films upon the eyes, and the fat is thought to improve the sight.

The gall of the eagle, which tests its young, as already stated, by making them look upon the sun, forms, with attic honey, an eye-salve which is very good for the cure of webs, films, and cataracts of the eye. A vulture's gall, too, mixed with leek-juice and a little honey, is possessed of similar properties; and the gall of a cock, dissolved in water, is employed for the cure of argema and albugo: the gall, too, of a white cock, in particular, is recommended for cataract. For short-sighted persons, the dung of poultry is recommended as a liniment, care being taken to use that of a reddish color only. A hen's gall, too, is highly spoken of, and the fat in particular, for the cure of pustules upon the pupils, a purpose for which hens are expressly fattened. This last substance is marvelously useful for ruptures of the coats of the eyes, incorporated with the stones known as schistos and hæmatites. Hens' dung, too, but only the white part of it, is kept with old oil in boxes made of horn, for the cure of white specks upon the pupil of the eye. While mentioning this subject, it is worthy of remark, that peacocks swallow their dung, it is said, as though they envied man the various uses of it. A hawk, boiled in oil of roses, is considered extremely efficacious as a liniment for all affections of the eyes, and so are the ashes of its dung, mixed with attic honey. A kite's liver, too, is highly esteemed; and pigeon's dung, diluted with vinegar, is used as an application for fistulas of the eyes, as also for albugo and marks upon that organ. Goose gall and duck's blood are very useful for contusions of the eyes, care being taken, immediately after the application, to anoint them with a mixture of wool-grease and honey. In similar cases, too, gall of partridges is used, with an equal quantity of honey; but where it is only wanted to improve the sight, the gall is used alone. It is generally thought, too, upon the authority of Hippocrates, that the gall to be used for these purposes should be kept in a silver box.

Partridges' eggs, boiled in a copper vessel, with honey, are curative of ulcers of the eyes, and of glaucoma. For the treatment of bloodshot eyes, the blood of pigeons, ring-doves, turtle-doves, and partridges

is remarkably useful; but that of the male pigeon is generally looked upon as the most efficacious. For this purpose, a vein is opened beneath the wing, it being warmer than the rest of the blood, and consequently more beneficial. After it is applied, a compress, boiled in honey, should be laid upon it, and some greasy wool, boiled in oil and wine. Nyctalopy, too, is cured by using the blood of these birds, or the liver of a sheep—the most efficacious being that of a tawny sheep—as already stated by us when speaking of goats. A decoction, too, of the liver is recommended as a wash for the eyes, and, for pains and swellings in those organs, the marrow, used as a liniment. The eyes of a horned owl, it is strongly asserted, reduced to ashes and mixed in an eye-salve, will improve the sight. Albugo is made to disappear by using the dung of turtle-doves, snails burnt to ashes, and the dung of the cenchris, a kind of hawk, according to the Greeks. All the substances above mentioned, used in combination with honey, are curative of argema: honey, too, in which the bees have died, is remarkably good for the eyes.

A person who has eaten the young of the stork will never suffer from ophthalmia for many years to come, it is said; and the same when a person carries about him the head of a dragon: it is stated, too, that the fat of this last-named animal, applied with honey and old oil, will disperse incipient films of the eyes. The young of the swallow are blinded at full moon, and the moment their sight is restored, their heads are burnt, and the ashes are employed, with honey, to improve the sight, and for the cure of pains, ophthalmia, and contusions of the eyes.

Lizards, also, are employed in numerous ways as a remedy for diseases of the eyes. Some persons enclose a green lizard in a new earthen vessel, together with nine of the small stones known as "cinædia," which are usually attached to the body for tumors in the groin. Upon each of these stones they make nine marks, and remove one from the vessel daily, taking care, when the ninth day is come, to let the lizard go, the stones being kept as a remedy for affections of the eyes. Others, again, blind a green lizard, and after putting some earth beneath it, enclose it in a glass vessel, with some small rings of solid iron or gold. When they find, by looking through the glass, that the lizard has recovered its sight, they set it at liberty, and keep the rings as a preservative against ophthalmia. Others employ the ashes of a lizard's head as a substitute for antimony, for the treatment of eruptions of the eyes. Some recommend the ashes of the green lizard with a long neck that is usually found in sandy soils, as an application for incipient defluxions of the eyes, and for glaucoma. They say, too,

that if the eyes of a weasel are extracted with a pointed instrument, its sight will return; the same use being made of it as of the lizards and rings above mentioned. The right eye of a serpent, worn as an amulet, is very good, it is said, for defluxions of the eyes, due care being taken to set the serpent at liberty after extracting the eye. For continuous watering of the eyes, the ashes of a spotted lizard's head, applied with antimony, are remarkably efficacious.

The cobweb of the common fly-spider, that which lines its hole more particularly, applied to the forehead across the temples, in a compress of some kind or other, is said to be marvelously useful for the cure of defluxions of the eyes: the web must be taken, however, and applied by the hands of a boy who has not arrived at the years of puberty; the boy, too, must not show himself to the patient for three days, and during those three days neither of them must touch the ground with his feet uncovered. The white spider with very elongated, thin, legs, beaten up in old oil, forms an ointment which is used for the cure of albugo. The spider, too, whose web, of remarkable thickness, is generally found adhering to the rafters of houses, applied in a piece of cloth, is said to be curative of defluxions of the eyes. The green scarabæus has the property of rendering the sight more piercing of those who gaze upon it. Hence it is that the engravers of precious stones use these insects to steady their sight.

BOOK XXXII. CHAP. 24.—REMEDIES FOR DISEASES OF THE EYES AND EYE-LIDS. TWO REMEDIES DERIVED FROM THE FAT OF FISHES. THE CALLIONYMUS: THREE REMEDIES. THE GALL OF THE CORACINUS: ONE REMEDY. THE SÆPIA: TWENTY-FOUR REMEDIES. ICHTHYOCOLLA: FIVE REMEDIES.

The fat of all kinds of fish, both fresh-water as well as sea fish, melted in the sun and incorporated with honey, is an excellent improver of the eye-sight; the same, too, with castoreum, in combination with honey. The gall of the callionymus heals marks upon the eyes and cauterizes fleshy excrescences about those organs: indeed, there is no fish with a larger quantity of gall than this, an opinion expressed too by Menander in his Comedies. This fish is known also as the "uranoscopos,"* from the eyes being situated in the upper part of the head. The gall, too, of the coracinus has the effect of sharpening the eysight.†

* "Gazer at heaven."
† See herein "**Tobit.**"

The gall of the red sea-scorpion, used with stale oil or attic honey, disperses incipient cataract; for which purpose, the application should be made three times, on alternate days. A similar method is also employed for removing indurations of the membrane of the eyes. The surmullet, used as a diet, weakens the eyesight, it is said. The sea-hare is poisonous itself, but the ashes of it are useful as an application for preventing superfluous hairs on the eyelids from growing again, when they have been once pulled out by the roots. For this purpose, however, the smaller the fish is, the better. Small scallops, too, are salted and beaten up with cedar resin for a similar purpose, or else the frogs known as "diopetes" and "calamitæ," are used; the blood of them being applied with vine gum to the eyelids, after the hairs have been removed.

Powdered shell of sæpia, applied with woman's milk, allays swellings and inflammations of the eyes; employed by itself it removes eruptions of the eyelids. When this remedy is used, it is the practice to turn up the eyelids, and to leave the medicament there a few moments only; after which, the part is anointed with oil of roses, and the inflammation modified by the application of a bread-poultice. Powdered bone of sæpia is used also for the treatment of nyctalopia, being applied to the eyes with vinegar. Reduced to ashes, this substance removes scales upon the eyes: applied with honey, it effaces marks upon those organs: and used with salt and cadmia, one drachma of each, it disperses webs which impede the eyesight, as also albugo in the eyes of cattle. They say, too, that if the eyelids are rubbed with the small bone taken from this fish, a perfect cure will be experienced.

Sea-urchins, applied with vinegar, cause epinyctis to disappear. According to what the magicians say, they should be burnt with vipers' skins and frogs, and the ashes sprinkled in the drink; a great improvement of the eyesight being guaranteed as the sure result.

"Ichthyocolla" is the name given to a fish with a glutinous skin; the glue made from which is also known by the same name, and is highly useful for the removal of epinyctis. Some persons, however, assert that it is from the belly of the fish, and not the skin—as in the case of bull glue—that the ichthyocolla is prepared. That of Pontus is highly esteemed: it is white, free from veins or scales, and dissolves with the greatest rapidity. The proper way of using it is to cut it into small pieces, and then to leave it to soak in water or vinegar a night and a day, after which it should be pounded with sea-shore pebbles, to make it melt the more easily. It is generally asserted that this substance is good for pains in the head and for tetanus.

The right eye of a frog, suspended from the neck in a piece of cloth made from wool of the natural color, is a cure for ophthalmia in the right eye; and the left eye of a frog, similarly suspended, for ophthalmia in the left. If the eyes, too, of a frog are taken out at the time of the moon's conjunction, and similarly worn by the patient, enclosed in an egg-shell, they will effectually remove indurations of the membranes of the eyes. The rest of the flesh applied topically, removes all marks resulting from blows. The eyes, too, of a crab, worn attached to the neck, by way of amulet, are a cure for ophthalmia, it is said. There is a small frog which lives in reed-beds and among grass more particularly, never croaks, being quite destitute of voice, is of a green color, and is apt to cause tympanitis in cattle, if they should happen to swallow it. The slimy moisture on this reptile's body, scraped off with a spatula and applied to the eyes, greatly improves the sight, they say: the flesh, too, is employed as a topical application for the removal of pains in the eyes.

Some persons take fifteen frogs, and after spitting them upon as many bulrushes, put them into a new earthen vessel: they then mix the juices which flow from them, with gum of the white wine, and use it as an application for the eye-lids; first pulling out such eye-lashes as are in the way, and then dropping the preparation with the point of a needle into the places from which the hairs have been removed. Meges used to prepare a depilatory for the eye-lids, by killing frogs in vinegar, and leaving them to putrify; for which purpose he employed the spotted frogs which make their appearance in vast numbers during the rains of autumn. Ashes of burnt leeches, it is thought, applied in vinegar, are productive of a similar effect; care must be taken, however, to burn them in a new earthen vessel. Dried liver, too, of the tunny, made up into an ointment, in the proportion of four denarii, with oil of cedar, and applied as a depilatory for nine months together, is considered to be highly effectual for this purpose.—(T. H. S.)

Plugging of the central artery of the retina. See p. 4287, Vol. VI of this *Encyclopedia*.

Plumbi acetas. See **Lead acetate,** p. 7027, Vol. IX of this *Encyclopedia*.

Plumbism. Saturnism. Leading. See *Lead poisoning,* under **Neurology of the eye**; p. 8342, Vol. XI of this *Encyclopedia*.

Attention may also be drawn to the investigations of S. McMurray (*Ophthalmoscope,* November, 1915; abstract *Annals of Ophthal.*, p. 117, Jan., 1916) who gives the results obtained from the examination of the eyes of twenty-two cases of plumbism. He was able to follow up sixteen of the cases. As a rule the patient complains of

headache, and often of sudden mistiness and the appearance of cobwebs before the sight. All showed at one time or another contraction of the visual field of from five to twenty-five degrees. More remarkable than the contraction was the fact that it varied in every case, apparently having an intimate connection with the acuity of vision and with the degree of headache.

Three showed a central scotoma for red and blue.

Seven showed a relative scotoma for blue.

Ten showed a contraction of the field for blue, and of these, three showed an actual interlacing of red and blue.

Three had paresis of the external rectus, and nine had deficiency of accommodation.

While there was no gross lesion of the fundus present, as a rule there was considerable variation in the appearance of the retina, especially immediately after severe headaches or sickness.

At one time the choroidal vessels may be seen quite clearly, the edge of the disc and the lines of the retinal vessels may be seen distinctly, then, perhaps on the next day, the choroidal vessels may disappear, the retina seem swollen and hazy, and the vessels become indistinct. As a rule the extent of the contraction of the field is in proportion to the edema of the retina. A case is reported in detail as showing very well the different phases—apparently dependent entirely upon vascular changes and not associated with neuritis.

A man, aged forty-two years, a very moderate smoker, complained of attacks of colic followed by "foggy" vision for a few days each time. Vision, w. c. 6/12 in each eye. Central scotoma for blue, red and green. Form field contracted ten degrees in each eye. Ten days later, following an attack, vision was reduced to 6/20, and the fields contracted to thirty degrees. Nasally and below there was a sector-like defect reaching to the fixation point. The central scotomata were, if anything, slightly enlarged. There was no gross lesion of the fundus, but there was distinct retinal irritability, and the retina appeared hazy and edematous. The choroidal vessels, which had been clearly seen, were now imperceptible. The disc edges were blurred and indefinite. Three days later the vision had improved to 6/12, the fields were contracted only ten degrees, and the sector scotoma disappeared. Similar conditions were found present each time after three subsequent attacks. The blood pressure was usually increased about twenty millimeters after the attacks.

The writer finds that so long as the patient continues work in the lead process the symptoms persist, no matter how vigorous the treatment, but when the occupation has been changed to a nonlead one,

and the blood pressure reduced, there is a gradual disappearance of all symptoms. See, also, **Toxic amblyopia.**

Plum tree, The. *Prunus domestica.* Plum-tree resin was used in the times of Pliny the elder as an adjuvant in various ophthalmic prescriptions.—(T. H. S.)

Plurilocular. Same as multilocular.

Pneuma. See **Galen.**

Pneumobacillus of Friedländer. See **Bacteriology of the eye,** p. 783, Vol. II, as well as **Bacillus pneumoniæ friedländeri,** p. 742, Vol. II of this *Encyclopedia.*

Pneumocele of the Sac. See **Lachrymal diseases.**

Pneumococcus, Ocular relations of the. The divisions of this heading have already been discussed, frequently under **Bacteriology of the eye,** p. 763, Vol. II of this *Encyclopedia;* also under **Cornea, Serpent ulcer of the,** p. 3450, Vol. V; as well as under such captions as **Optochin,** p. 9095, Vol. XII.

To these observations are here added a few others of more recent date.

J. Cropper (*British Med. Journ.,* p. 41, July 8, 1916) reports a case of *pneumococcus conjunctivitis* in which the infection was pure—that is to say, no other organism appeared on culture—and to which there was a short and satisfactory ending on treatment: A. B., aged 45, a medical man who had previously suffered from a troublesome nasal and pharyngeal catarrh of the left side, was seized on March 18th with a well-marked conjunctivitis in the left eye. The eye was quite well the night before, but on the following morning there was not only pain and irritation, but a well-marked bead of pus collected at the inner canthus, which re-formed every fifteen or twenty minutes.

Slides of the pus showed that almost every leucocyte contained one or more diplococci. No other organism was seen, nor did any other grow in the culture.

The eye was thoroughly irrigated with silver nitrate solution, grs. v to ℥j (1 per cent.); the upper lid was well raised and the lower brushed with a swab of wool; the silver solution was not neutralized with salt.

The lids swelled up considerably, but next morning the pus had entirely ceased. Fresh eusol solution, 0.16 per cent., was dropped into the eye, and caused comparatively little pain. This was repeated the same afternoon, but caused considerably more inflammation and pain, the conjunctiva becoming somewhat injected and purple in color.

The eusol was then discontinued and warm boric douches given four or five times daily. This produced excellent results, and a slide of

the slightly purulent discharge next day—that is, on the fourth day—showed no organism whatever under the microscope.

Captain Rentoul, R. A. M. C., examined the slides and made the necessary cultures. His report is as follows:

"The smear on the slide showed pneumococcus in pure culture. Some were in the pus cells, but most were lying free. They all had marked eapsules. The swab was used for planting out. Here, again, I obtained a pure growth of pneumococcus.

The interesting points to notiee were:

1. So pure a growth of pneumocoeci in a direct smear.
2. So pure a growth on culture.
3. On the fourth day I again examined a smear and found no organisms.
4. The fact that severe cases of penumocoecic fever had occurred in the neighborhood. In these cases the only symptoms were malaise, and a temperature of 102° to 104°, ending in a few days by crisis; in all these eases I grew a typical pure pneumococcus from the blood (5 c. cm.) and urine."

The treatment of *pneumococcus ulcer of the cornea* is the subject of a very practieal essay by Maitland Ramsay (*Ophthal. Rec.*, September, 1915.) He says that first aid in such a case consists in washing out the conjunctival sac with a warm solution of boric acid, instilling a few drops of a 2 per eent. solution of cocaine, examining the eye carefully by focal illumination, removing any foreign body from beneath the eyelids or from the surface of the cornea, applying an ointment of 1 per cent. atropine, 2 per cent. cocaine and 3 per cent. iodoform, and covering the eye with a carefully adjusted compress and bandage.

The technique of further treatment is as follows: Ethylhydrocuprein hydrochloride, also known by the trade name of optochin, a white salt readily soluble in water, is employed in 1 or 2 per cent. aqueous solution. Before it is used, the floor of the ulcer should be thoroughly washed with a lotion, eontaining chinosol (1 in 4,000), or quinine hydrochloride (3 grains to 1 fluid ounce), diluted with an equal quantity of warm water, and the boundaries of the uleer should be outlined by staining with an alkaline solution of fluorescein. This done, a swab of sterilized woolen cotton, sufficiently large to cover the whole of the ulcerated surfaee, and saturated with a 1 per cent. aqueons solution of the optoehin, shonld be applied to the ulcer, and kept in firm contact with its floor and margin for about two minutes. Should the patient be sensitive, it is well to instill eocaine drops beforehand, because the applieation of the optochin causes sharp burning

pain lasting for from five to ten minutes. That irritation, however, soon lessens, and by the end of fifteen minutes there is complete anesthesia of the cornea, which will last for fully half an hour. These applications should at first be repeated two or three times daily, the good effect being maintained by instilling a few drops of 1 per cent. solution of optochin every hour during the days, while during the night, a 1 per cent. optochin and atropine ointment may be applied as often as possible without interfering with sleep. Ethylhydrocuprein is often applied by simple instillation alone, but the use of the swab and the hourly instillations combined will be found much more efficacious and satisfactory.

A rare case of *pneumococcus choroiditis* is reported by J. G. Clegg (*Ophthalmoscope,* June, 1915.) It occurred in a young man 27 years of age. Examination of the fundus after rapid failure of vision showed the media clear, but the disc was slightly blurred and the retinal vessels were full. Two whitish areas with fairly well-defined margins were visible, one above and one below the fovea. The upper one was roughly oval, and the vertical long diameter was about one and one-half times that of the optic disc; the lower was crescentic, with the concavity upward, also one and one-half disc diameters in length.

The condition so closely resembled a tuberculous lesion that injections of bovine and human tuberculin were given. The eye became more irritable, the cornea was hazy, anterior chamber deep, pupil wide with large dilated vessels in the iris; vitreous full of opacities, areas of exudation very indistinct, and disc not visble. Panophthalmitis developed and the eye was enucleated.

The pneumococcus alone was found in the specimens. The vitreous and choroid, after being kept in a closed bottle in the cold for six days, during which the cocci would die, were then introduced under the skin of a guinea pig, which was afterwards killed and examined, but no sign of tubercle was found. The other eye remained perfectly healthy.

One of the most recent and most complete accounts of pneumococcal infection of the eye is given by N. C. Riley (*Ophthalmoscope,* p. 232, May, 1916) to which the reader is referred.

Pneumococcus ulcer. See **Cornea, Serpent ulcer of the.**

Pneumo-massage of the eyeball. See **Massage.**

Pneumonia, Eye affections due to. The bacterial cause of lobar pneumonia—the pneumococcus—may invade all the ocular tissues, even the lens, producing those morbid changes described under the usual captions. See, e. g., **Metastasis, Ocular,** p. 7673, Vol. X of this *Encyclopedia.*

Fejer (*Centralbl. f. pkt. Augenheilk.,* June, 1913) described a suppurative endophthalmitis after pneumonia. A woman, aged 50 years, during an attack of pneumonia developed an inflammation of one eye, which gradually came to present the picture of a suppurative panophthalmitis. As the illness was fatal, it was impossible to make any investigations of the causal organisms.

Purtscher (*Klin. Monatsbl. f. Augenheilk.,* January, 1913), reported a case of metastatic ophthalmia in a patient who went through an attack of pneumonia shortly after the appearance of a thrombosis of a branch of the central vein of one eye. The other eye became inflamed soon after the beginning of the pulmonary trouble. Pneumococci were recovered from cultures made from the suppurating eye. Increase of tension and ring abscess formation also occurred.

Robert Pitfield (*N. Y. Medical Record,* p. 813, May 15, 1915) records a metastatic, bilateral pneumococcic panophthalmitis that developed on the eleventh day or earlier. Spinal puncture showed pneumococcic globulin. On the fourteenth day the corneæ were very hazy, the eyeballs looking like "boiled onions," and the lids very edematous. The patient, a young girl, died on the sixteenth day, with a well developed meningitis.

Pocken. (G.) Small-pox.

Podagra. Gout, especially of the articulations of the foot or the great toe.

Podophthalmic. PODOPHTHALMOUS. Said of crustaceans that have eyes borne at the extremity of long movable peduncles.

Podophyllin, Ocular effects of. The best account of this matter is furnished by Chiari (*Clinica oculistica,* vol. xi, p. 345, 1910; abstract in the *Oph. Review,* Feb., 1911) who points out that it has been known now for some time that the resin of podophyllin (*Podophyllum peltatum*) is capable of setting up very serious irritation of cornea, conjunctiva, and iris; both Sureau and Rocca-Serra have written upon the subject (1902), the latter in particular giving an account, accurate so far as it goes, but hardly full, of the symptoms set up, and doing little more than hint at lesions of other parts; he had apparently conducted no experimental research on the subject.

Chiari was called to see a chemist, whose story was that three days before he and two others had been engaged in dividing, weighing, and packing up a large quantity of podophyllin; being aware that the substance had an irritant effect, he had protected his nose and throat from its action, but he had taken no precaution in regard to his eyes. The patient, who was confined to bed, complained of intense itchiness, burning and feeling of dryness in the eyes, although there was copious

lachrymation; there was severe photophobia, and it was found impossible to open the swollen, tumefied, lids. The skin of the lids was reddened and edematous, but otherwise showed no abnormality at all; the conjunctiva was in a similar state, but though chemosed showed no hemorrhages. Each cornea was faintly white and opalescent, owing to a diffuse infiltration, which condition was worse in the left eye near the centre of the cornea than in the right. The epithelium of the cornea had become semi-opaque and edematous in parts, but with no actual loss of substance; there was partial anesthesia and diminution of the reflex. There were no deposits on Descemet's membrane; the two pupils were equally miotic and immobile either to light or to accommodation. The fundus showed nothing abnormal, the lens was transparent and the tension was not raised. The treatment adopted was the use of atropin in 1 per cent. solution, with hot fomentations. The other two persons who had been working along with the patient were similarly affected, suffered in an exactly similar way, but to a less degree. Gradually and fairly rapidly the cornea began to clear, the right pupil at last became larger, and the photophobia became much less. There was perhaps a very slight degree of hyperemia of the disc, the retina appeared healthy, only the veins were decidedly engorged; there was no color-blindness, no restriction of the fields and no central scotoma. On careful investigation, however, there was found an absolute scotoma in contact with the blind spot, the area being a fairly regular oval; the condition was symmetrical in position and nature in the two eyes, though of smaller area in the left. By the end of ten days the condition appeared to have returned to normal.

Rocca-Serra had already observed that powdered podophyllin, insoluble in water, is soluble in an alkaline medium, such as lachrymal secretion, and is capable then of seriously injuring the corneal epithelium and causing much photophobia, possibly by setting up an irritation of the nerve elements in the cornea. It is not improbable that upon the iris it acts as it does upon the intestinal glands, the iris being also a secreting organ, and that perhaps in this way a toxic effect was produced upon the optic nerve when the action was continued for a certain length of time.

Testing the action of podophyllin upon the enucleated eye of the rabbit, Chiari found indications of inflammatory reaction in cornea, iris and about the corneo-iridic angle; the ciliary processes were swollen too, but the lens remained uninjured.

Except for the dilatation of retinal vessels the fundus in neither eye presented any abnormality; there was no exudate, no anatomical changes to account for this symmetrical lesion in the fields of vision.

The association of the miosis with the corneal insensibility is striking, especially in view of Rocca-Serra's observations, both clinical and experimental, for he says that in the cases in which he obtained only a mild reaction the miosis lasted only so long as the phenomena of irritation of the fifth nerve—when the insensitiveness of the cornea was restored the pupil again became normal. It is noteworthy, further that the lowering of visual acuteness lasted after the disappearance of all external signs of irritation, and that this was so to a greater degree in the eye (right) in which the corneal disturbance was less severe.

Only the study of future cases can clear up the difficulties in regard to the mode of origin, toxic or otherwise; but all workers with the drug should be warned to be careful in handling it.

Poincaré, Emile-Léon. A well known French physiologist and ophthalmologist. Born Aug. 16, 1828, at Nancy, France, he received the degree of M. D. at Paris in 1852, presenting as dissertation "De l'Ophtalmie Purulente des Nouveaux-nés." Settling as general physician in Nancy, he there taught physiology from 1858 till 1872. From 1870 until his death he was also professor of hygiene. He died Sep. 21, 1892.—(T. H. S.)

Point. In alphabets and print for the blind (q. v.), point is sometimes used to mean an embossed dot. *Point* or *Point unit* is also used to mean the space which is or might be occupied by one dot. Its length and width are equal to the space between two dots in adjacent positions, center to center.

Point, Absolute near. The nearest point to which a single eye can be accommodated and still retain distinct vision.

Point, Cardinal. Any one of a set of six points of reference in the eye. They are (1) the anterior focus, or anterior focal point, whose rays, coming from the retina and parallel to the axis of the eye, are brought to a focus; (2) the posterior focus, or posterior focal point, on the retina, at which rays converge parallel to the axis, and coming from the front of the eye; (3 and 4) the principal points, in the anterior chamber, behind the cornea and on the optic axis; (5 and 6) the nodal points, near the posterior surface of the lens. See p. 1413, Vol. II of this *Encyclopedia*.

Point, Corresponding. Points upon the two retinæ whose impressions unite to produce a single perception.

Point de regard. (F.) Fixation point.

Point, External orbital. The most prominent point at the outer edge of the orbit, immediately above the fronto-malar suture.

Point, Eye. An eye-spot; an ocellus.

Point, Far. The farthest point of distinct vision; situated in the emmetropic eye at infinity, in the myopic eye at a finite distance in front of the eye, and in a hypermetropic eye situated beyond infinity (i. e., behind the eye).

Point, Fixation. That point on the visual axis at which an object is most clearly seen.

Point, Focal. The point of convergence of light-rays.

Pointilism. A method employed by artists in which pigments are laid down in minute areas or spots or lines so that when the picture is viewed from a certain distance, the different hues act on the same nerve endings of the retina and therefore produce the same effect as if they had been superimposed, as by the use of Maxwell's discs. Thus, if a white surface be dotted over with red, green, and violet, or any other primary colors, or with red and greenish-blue, or any other complementary colors, the surface at a certain distance will appear grayish-white. If, in any of the combinations, one hue will be in preponderance of the others, the gray will become correspondingly tinted, so that a complete picture may be built up of areas which on close inspection are a mosaic of pure colors but appear at a distance as tinted grays.

Point lointain. (F.) Far point.

Point, Near. The nearest point at which the eye can distinctly perceive an object; the nearest point of clear vision.

Point, Near, Absolute. The near-point for either eye alone with accommodation relaxed.

Point, Near, Relative. The near-point for both eyes with the employment of accommodation.

Point of the compass. An angular unit equal to $11\frac{1}{4}°$, being one-eighth of a right angle.

Point of dispersion. In optics, the virtual focus.

Point of distance. In perspective that point of a picture where the visual rays meet.

Point of fixation. See **Point, Fixation.**

Point of incidence, refraction, or reflection. That point upon a surface at which a ray of light impinges, or is refracted, or reflected.

Point of regard. A point at which the eye is directly looking.

Point of reversal. In skiascopy the point at which the shadow begins to move in the direction opposite to that it formerly followed.

Point of sight. The position from which anything is observed; the centre of projection.

Point of the retina, Physiological middle. The fovea centralis.

Point, Reflection. The point from which a ray of light is reflected.

Point, Relative near. The near-point for both eyes with the employment of accommodation.

Point, Refraction. The point at which a ray of light is refracted.

Point, Supranasal. The middle-point of the transverse supra-orbital line.

Points. See **Pencils.**

Points, Cardinal. See p. 1413, Vol. II of this *Encyclopedia.*

Points, Corresponding. See **Correspondence of the retina,** p. 3539, Vol. V of this *Encyclopedia.*

Points, Disparate retinal. Those points on the retina the images of which are not concentrated on the same point, but projected to different points in space.

Points, Focal. The anterior and posterior principal foci of a compound dioptric system. The anterior (or first) focal point of the eye is the point to which rays that are parallel in the vitreous would converge in front of the eye: the posterior (or second) focal point is the point of the back of the eye to which rays that are parallel as they impinge upon the cornea converge.

Points, Identical. The corresponding points on the retinæ of the two eyes.

Points, Identical, of the retina. See **Points, Corresponding.**

Points, Lachrymal. The puncta lacrymalia: the outlets of the lachymal canaliculi.

Points lacrymaux. (F.) Lachrymal puncta.

Points, Nodal. Two points called respectively the first (or anterior) nodal point and the second (or posterior) nodal point, situated on the optical axis of a dioptric system, and so related that every incident ray which is directed toward the first point is represented after refraction by a ray emanating from the second point and having a direction parallel to that of the incident ray. The nodal points of the schematic human eye very nearly coincide, the anterior being situated about 7 mm. behind the cornea (or just in front of the posterior pole of the lens), and the second 7.33 mm. behind the cornea, or just behind the posterior pole of the lens.—(*Foster.*)

Points, Principal. Two points situated on the optical axis or the line connecting the centers of curvature of the various refracting surfaces of a compound dioptric system, and so related that the final emergent ray bears the same relation to the second (or posterior) principal point that the initial or incident ray would bear to the first (or anterior) principal point after having undergone refraction through a single refracting surface of determinate curvature. In the schematic human eye, when at rest, the anterior principal point

is situated at 1.75 mm., the posterior at 2.11 mm. behind the posterior surface of the cornea.—(*Foster.*) See **Physiological optics.**

Point, Supra-orbital. In neuralgia, a tender spot, just above the supra-orbital notch.

Poison ivy, Ocular effects of. Sherer (*Oph. Year-Book,* p. 106, 1916) has reported a case of this not uncommon condition. They took the form both of conjunctivitis and keratitis, associated with a severe *dermatitis venenata* which involved the skin of the periorbital region. There was intense inflammation of the entire conjunctiva. The membrane was edematous and presented minute hemorrhages. No purulent secretion was present. In the second week the cornea presented minute dots confined to the periphery. Complete recovery occurred. See, also, p. 3836, Vol. V of this *Encyclopedia.*

Poisoning, Ocular indications of. See *supra,* **Legal relations of ophthalmology,** in middle third of the section.

Poisons producing amaurosis and amblyopia. See **Toxic amblyopia,** and under the various agents.

Poland, Alfred. A celebrated London surgeon, who, for a very short time, engaged in the practice of ophthalmology. Born in London in 1822, he became a special scholar of Aston Key in Guy's Hospital. In 1843 he became a Member, and in 1847 a Fellow of the R. C. S. of England. In 1845 he was made anatomical prosector at Guy's, and, a few years later, professor of surgery. For a number of years he was chosen surgeon at Moorfields, and, in 1861, after the retirement of France, he accepted the supervision of the Ophthalmic Section of Guy's Hospital. Soon, however, he abandoned ophthalmic work entirely. In the course of an operation, he became infected with pus, and, five years later, after much ill-health and suffering, he died, Aug. 21, 1872, aged only 51.

Poland's ophthalmic writings are as follows:

1. On the nerves of the Orbit in Mammalia and Man. (Crowned by the College of Surgeons with their triennial prize.)
2. Anophthalmos. (O. H. R. I., p. 1854.)
3. Medico-Legal Observations. (*Ibid.,* III, p. 198, 1861-1862.)
4. Protrusion of the Eyeball. (*Ibid.,* I, p. 21, p. 68, and II, p. 216.)

—(T. H. S.)

Polar cataract. Anterior polar and posterior polar cataract. See p. 1463, Vol. II and p. 1572, Vol. III of this *Encyclopedia.*

Polar clock. An optical apparatus which indicates the hour of the day by means of the state of polarization of the light from the sky.

Polarimeter. An instrument for measuring the amount of angular direction of polarized light.

Polariscope. An instrument used for investigating the phenomena of polarization and the changes produced in these phenomena by the interposition of certain substances in the path of the polarized ray. It consists essentially of a polarizer which puts the light in a state of polarization, and of an analyzer which, by quenching the polarized ray when placed in certain positions, shows the location of the plane of polarization. A change in the location of this plane or the presence of other phenomena induced by the interposition of a substance between the polarizer and analyzer is indicative of the structure or composition of the substance so interposed.—(*Foster.*)

Polariscope, Projecting. An instrument used for the detection of color-blindness. See **Color-sense, Spectroscope test of the.**

Polarization. In light, a term applied to a group of phenomena at a time when the corpuscular or emission theory of light held sway over the minds of men. It is not now regarded as an appropriate term. There is nothing of the nature of endedness in a ray of polarized light. The essential property is rather one of "sidedness."

There are several kinds of polarized light—namely, plane, circular, elliptic; and these can all be expressed with great ease in terms of the wave theory of light as elaborated by Fresnel.

Plane polarized light is obtained most perfectly by means of Iceland spar; for when light is passed through this crystal, the two rays into which the incident ray is divided are both polarized, the so-called planes of polarization being perpendicular to one another. Plane polarized light may also be obtained, although not so purely, by reflection from the surface of a transparent substance, such as water, glass, crystal and the like.

The nature of the phenomenon is perhaps most easily understood when the experiment is made with a special modification of the Iceland spar known as the Nicol prism. This was invented by an Edinburgh (Scotland) chemist in 1828. He showed how, by cutting the Iceland spar along one of the diagonal faces and cementing the two halves together again with Canada balsam, he was able to get rid of the ordinary ray. In 1837 Edward Sang, of Edinburgh, Scotland, first gave the true explanation of this extinction of the ordinary ray—it was totally reflected at the surface of the Canada balsam, while the extraordinary ray passed through. Now this ray is a plane polarized ray. When a second Nicol is placed in front of the first with similar faces parallel the ray through the first will also pass through the second. But if either prism is rotated round the ray as axis through a right angle, the ray which has passed through the first Nicol is completely stopped by the second Nicol, although both crystals are almost

perfectly transparent to ordinary light. On continuing the rotation from the position of extinction the ray begins again to pass through the second Nicol, and after another right angle has been turned through the ray passed through both prisms with the original intensity. Thus at every successive quarter revolution of either of the prisms from the first position of maximum brightness, there is alternation of darkness and brightness of the transmitted light. Instead of using two Nicol prisms we may use a reflecting transparent surface and one prism.

All these phenomena and many others of a more complex nature are simply co-ordinated in terms of the wave theory of light. According to this theory the vibrations which constitute light take place at right angles to the direction of propagation of the ray. An analogy is a tightly stretched wire, vibrating so as to produce a musical note. The vibrations take place at right angles to the string—that is, at right angles to the direction in which the waves are passing along the string. It matters not whether we follow Fresnel and think of the vibrations of light as being motions in an elastic medium, or follow Maxwell and regard the vibrations as being electric and magnetic, the general conclusions are the same. In a ray of common unpolarized light the vibrations take place in all possible directions perpendicular to the ray; whereas in plane polarized light the vibrations are confined to a definite plane containing the ray. The double refracting property of Iceland spar may then be described as having the effect of decomposing the vibrations of the incident ray into mutually perpendicular components, which pass on as two independent rays with vibrations taking place in planes perpendicular to one another. In the Nicol prism, the one ray is stopped and the other is allowed through. Thus the Nicol acts as a kind of sieve which allows the transmission of vibrations only in one definite plane; and the position of this plane is determined by the position of the crystal. The action of two "crossed Nicols" is now evident. Let the first Nicol be set so as to transmit, say, vertical vibrations; and the second set so as to transmit only horizontal vibrations. When set in line with one another, what the one Nicol transmits the other stops. If the one Nicol be now rotated, the planes of vibrations possible for transmission by the two Nicols will not be perpendicular to one another; a certain component of the plane polarized ray which has passed through the first Nicol will pass through the second. This component will get larger as the Nicol is rotated further, until when they are "parallel" the light is practically wholly transmitted.

Of the many other beautiful phenomena of polarized light, we have

space only for mention of one, namely, what is known as rotatory polarization. Let a beam of light be passed through two Nicols, or two suitable slices of tourmaline, which show exactly the same phenomena. Adjust the one Nicol until the light is cut off. Then insert between the two crossed Nicols a thin disc of quartz. Immediately light will appear to pass through the second prism; and this light will be colored if the quartz is not too thick. The color is found to depend on the thickness of the disc of quartz. If one of the Nicols is rotated the color of the transmitted light will pass through a great variety of tints; and in no position of the Nicols will there be complete extinction of the transmitted ray. The simple explanation of this striking phenomenon is that the quartz rotates the plane of polarization of each individual colored constituent of white light through a different angle. The second Nicol, therefore, is no longer crossed with regard to them. A certain proportion of each colored ray will pass through the Nicol; but because of the different amounts of rotation of the plane of vibration for the different colored rays, these will be transmitted in varying degrees of intensity, and the resultant tint will be determined by that which passes through in greatest abundance. The same property of rotation of the plane of polarization is possessed by many other substances, although none to such a degree as quartz. Solutions of sugar have this property, which is made a practical test of the strength of the solution in the instrument called the saccharimeter.—(*Standard Encyclopedia.*)

Polarization microscope. A microscope with a polarizing attachment.

Polarization photometer. A photometer which measures the intensity of a source of light by making use of the properties of polarized light.

Polarizing angle. See **Angle**; also **Polarization.**

Polarizing prism. A device which makes use of the refractive properties of certain substances to obtain polarized light. The most important is the Nicol, but there are many other modifications, such as Glan's, Foucauld's, Thompson's, Dove's, Prazmonsky's, etc.

Polariztrobometer. An instrument for measuring the rotation of the plane of polarization of light in traversing any medium. See **Half-shadow apparatus,** p. 5679, Vol. VIII of this *Encyclopedia.*

Pole. In any more or less spherical body, one of two opposite points of the surface in any way distinguished; or, when there is a marked equator, one of the two points most remote from it.

Pole, Anterior. The front or facial end of the antero-posterior axis of the crystalline lens.

Polemophthalmia. Military ophthalmia.

Polemoscope. A perspective or opera glass provided with a mirror so that persons may be scrutinized without obviously directing the glass towards them.

Pole of a lens or mirror. In *optics,* the point where the surface of a lens or mirror intersects the optical axis.

Poles of the eye. The anterior and posterior extremities of the optic axis.

Pole, Posterior. The posterior end of the antero-posterior axis of the lens.

Poliencephalitis, Ocular symptoms of. See **Neurology of the eye,** under the subsection *Encephalitis.*

Kaz (*Ophth. Rev.,* June, 1912) points out that Sydney Stephenson states that the form of paralytic squint which occurs suddenly in young children, either without known cause or after some general disease, is really a manifestation of poliencephalitis in an oculomotor form.

Kaz does not think that a poliencephalitis can be assumed to be present in every infantile paralytic squint, nor does he understand why an infectious disease such as diphtheria, should not directly affect the extraocular as well as the intraocular muscles without the necessity of assuming an intermediate poliencephalitis.

Two cases are reported which lead the author to think that Stephenson's hypothesis is frequently correct.

It is evident that in both cases there was the same underlying poliencephalitis, the cerebral form of so called infantile paralysis, which in the one case appeared in its ordinary form affecting the muscles of the extremity, in the other in the form of a paralysis of the external ocular muscle.

Torantola (*Riv. Ital. di Ottal.,* April, 1914) holds that many cases of poliencephalitis are confused with cases of intracranial tumor, on account of the similarity of symptoms, especially from double papillitis, and further that the importance of auto-intoxication from the intestinal tract as a cause of poliencephalitis has not been generally recognized.

He is of opinion that the immediate cause of the symptoms comes to the eye not from the brain along the sheath of the optic nerve, but is brought to the eye through the general circulation.

In several cases he corrected the diagnosis of cerebral tumor in favor of one of encephalitis. However, the symptoms are identical and it is certain that in the majority of cases, headache, vomiting and optic neuritis are found with cerebral tumor.

Poliencephalomyelitis. See the subsection *Encephalitis* under **Neurology of the eye.**

Poliomyelitis, Ocular symptoms of. See same under **Neurology of the eye.**

Posey and Swindells (*Oph. Year-Book,* p. 379, 1916) report four cases of *anterior poliomyelitis* in which important ocular complications accompanied the disease. A boy of 7, three weeks after beginning of the attack, complained of diplopia and later of failing vision. Lumbar puncture caused no improvement, and five weeks after the beginning of the attack he was found with optic atrophy, complete blindness, and loss of pupil reaction. Another boy of 7 developed paralysis of the muscles of the left side of the face, convergent squint, lagophthalmos, and epiphora. A boy of 5 was brought for marked ptosis following an attack of infantile paralysis six weeks previously. A boy of 7, seen on the third day of the attack, had complete external ophthalmoplegia with pupils and vision normal. After several weeks the ocular palsies went on to complete recovery.

Poliosis of the cilia. Canities. Premature bleaching or whitening of the eyelashes. An account of this rather rare affection is furnished by Vogt (*Tydsch. van Geneesk.,* Feb. 24, 1906). In one instance, a youth, aged 18, had iridocyclitis of both eyes for nine weeks, the affection having commenced five weeks previously. The patient showed a marked white discoloration of almost symmetrical tufts of the cilia of both upper eyelids, the lids and glands being normal. Some of the white cilia were full grown, others short and presented white apices on pigmented bases. The poliosis progressed within the following three weeks. No cause could be found, but an indirect one in the iridocyclitis.

See, also, **Cilia, Poliosis of the**, p. 2224, Vol. III, as well as p. 1382, Vol. II of this *Encyclopedia.*

Pollak, Simon. A distinguished American ophthalmologist, of foreign birth, founder of the first eye and ear clinic in St. Louis. Born at Prague, Bohemia, Apr. 14, 1814, he received his medical degree in 1835 at the University of Vienna. Two years later, he came to America, and, in 1838, began to practise at Nashville, Tenn. Here he remained for six years, and then removed to St. Louis, where he practised for fifty-eight years. In 1852 he, in conjunction with Yeatman, Eliot and others, founded the Missouri School for the Blind. He was also one of the founders, in 1850, of the St. Louis Academy of Science. Ten years later he instituted the eye and ear clinic at Mullanphy Hospital, the first of the kind in St. Louis.

Dr. Pollak, throughout the Civil War, was a member of the U. S. Sanitary Commission and of the Western Sanitary Commission.

He married in 1863 a daughter of Samuel Perry, of Cincinnati, by

whom he had two sons. He died Oct. 31, 1903, at his home in St. Louis, aged almost 90 years.—(T. H. S.)

Pollakiuria, Ocular relations of. Excessive and frequent micturition is claimed by W. W. Kahn (*Pre-sessional print, Ophthalmic Section, A. M. A.*, June, 1918) to be occasionally caused by refractive errors.

He says that for pollakiuria as a symptom of eye-strain there are at least two causes. One is the local pathologic change in one of the urinary organs, and the other is the hyperirritability of the nervous system caused by eye-strain. If the local lesion is dominant, no amount of correction of refraction will relieve the patient; only local treatment can do it. But when the local lesion is slight or negligible, the relief of the nervous system from the excess of nervous irritation will bring about a cure.

The disturbing cause in his series of cases was eye-strain, but that did not exclude malfunctions of other organs from having similar effects on the bladder.

He further concludes that: 1. Pollakiuria, or excessive frequency of micturition, must be strictly differentiated from polyuria and incontinence of urine. 2. In a great percentage of cases, pollakiuria is a neurosis, brought about by malfunction of a distant organ, especially the eye. 3. Contrary to the general medical opinion, pollakiuria is nearly as frequent in men as in women. 4. Before a surgical interference is tried, a careful examination of the refraction is indicated in all cases of pollakiuria.

Pollantin. Dunbar's serum. This agent is an antitoxic serum from horses treated with pollen toxin derived from the *rag weed* (*wild tansy*), *Ambrosia artimisifolia*. It is a clear, yellowish fluid, smelling of its preservative, 0.25 per cent. of phenol. It soon decomposes if exposed to air. It is used undiluted (or diluted one-half to one-fourth) as a daily collyrium in eye affections.

This remedy is also applied in dry form as snuff, the flowers of the "Golden-rod" having also been used. A number of favorable results from its use have been reported in the eye complications of "hay fever."

George S. Derby has found this agent of considerable value in vernal catarrh. It allays the irritation of the disease, although it has no curative effect. E. Gruening and others have used the same remedy and speak highly of it.

Polony. A French charlatan, of some real merit. He succeeded Dubois at Nîmes in 1737. The following advertisement of Polony in *"Le Courrier d'Avignon"* for the 24th of May, 1737, is translated by the present writer from the work of Truc et Pansier, *"Histoire de l'Oph-*

talmologie à l'Ecole de Montpellier,'' p. 271. This advertisement, by the way, is the only extant document concerning Polony. ''Sieur Polony, famous oculist established at Nîmes for several months and who has fixed his abode in the same quarters in which M. Dubois, also an oculist, formerly resided, has just depressed a cataract for M. Astruc, citizen of Lunel le Vieux in Languedoc, who was blind for a number of years. The operation was performed, with all the capacity and dexterity possible, in the space of five minutes. He it was who some time ago restored the sight to M. le Prieur de Sérignac, of the diocese of Uzè, to M. Nicolas, citizen of Bouzignes, and to another citizen of the same place. The two Siol brothers, of the city of Bagnols, to whom he has rendered the same service cannot sufficiently praise the skill of this man's hands. He has also performed divers other cures with success, such as cutting for stone, destroying cancers, etc. His operations are done in the presence of all such physicians and surgeons as can be got to attend.''—(T. H. S.)

Polso arterioso. (It.) Arterial pulse.

Polyaxial. Having several axes; multiaxial.

Polychrests. The chief homeopathic remedies; the most commonly used, with the largest pathogeneses which cover all parts of the body, acting deeply upon more than one of the bodily systems. See **Homœopathy in ophthalmology.**—(J. L. M.)

Polychroism. Pleiochroism. In crystals, such as some specimens of topaz, three distinct colors may be observed on looking through them along three rectangular axes. In intermediate directions intermediate tints may be observed.

Polychromate. A person who can distinguish many colors.

Polychromatic. (a) Many-colored. (b) Exhibiting a play of colors.

Polycoria. A malformation consisting of a multiplicity of pupils in the eye. See page 2853, Vol. IV of this *Encyclopedia.*

In the case described by Grilli (*Rivista Italiana di Ottalmologia,* June-July, 1912) the left eye had three openings in the iris and the right four; in the left eye the anterior surface of the lens showed no abnormality, but in the right the portion of the surface corresponding to the largest ''pupil,'' was the seat of deposit of pigment, resembling that left after iritis. In each eye below the openings, there was a yellow patch in the iris, the surface of which showed a waxy reflex; the iris surface generally showed little trace of crypts, and appeared atrophic.

A striking case is also recorded by H. Work Dodd on page 199, in the seventeenth volume of the *Transactions of the Ophthalmological Society of the United Kingdom.*

Polycythemia, Ocular signs of. Erythremia. See, also, p. 4516, Vol. VI of this *Encyclopedia;* as well as under **Cyanosis of the eye**; and under **Corkscrew vessels.**

J. Ascher (*Klin. Monatsbl. f. Augenheilk.,* 53, p. 388, 1914) found, as the most striking symptom of polycythemia in the eye, intense and diffuse hyperemia of the conjunctiva of both eyes, especially the palpebral. It had a more livid dark color than the more pinkish-red of conjunctivitis and was most intense at the lid borders. From the retrotarsal folds numerous dilated vessels spread into the ocular conjunctiva. It is distinguished from the ordinary conjunctival catarrh by the absence of irritation and secretion. Another symptom is the bluish discoloration of the sclera in consequence of the intense expansion and filling of the choroid with blood abounding in red blood corpuscles. One of the relatively slight subjective ailments of the patients is asthenopia, caused, as Behr found at an autopsy, by the pervasion of the ciliary muscle by choked blood-vessels and subsequent lowered function. Ascher sees another cause of this asthenopia in the thickening of the choroid by from 0.3 to 0.4 mm., which advances the retina with a decrease of refraction of from 1 to 1.5 D.

The ophthalmoscopic picture of the polycythemic fundus is pathognomonic. Fountain-like projection of the dark-colored and ectatic central vessels and the appearance of numerous, otherwise invisible, vessels. These crowd the fibers of the disc apart and create the aspect of choked disc of an elevation of from 2 to 3 D. The observation of these symptoms is of the greatest importance in the diagnosis of polycythemia and its therapy at a time when there are still prospects of a cure or at least improvement by venesection and proper diet.

The ocular symptoms of chronic polycythemia is the subject of a paper by de Schweinitz (*Oph. Year-Book,* p. 51, 1908). His case exhibited the changes described by others. The arteries were unchanged, the veins greatly enlarged, somewhat irregular, markedly tortuous and purplish in color. There were no retinal hemorrhages or extravasations.

In the case reported by Shoemaker (*Oph. Year-Book,* p. 276, 1912) the changes in the fundus were those of "typical inflammatory choked disc," identical it would seem with those frequently seen with intracranial disturbance.

Finally, C. Behr (*Klin. Monatsbl. f. Augenh.,* I, p. 672, 1911) has reported a case under observation five years, which was studied postmortem. The red corpuscle count was 8 to 10 millions and hemoglobin was 110 to 145 per cent. Death occurred from cardiac insufficiency. Clinically, as regards the eyes, the case was one of cyanosis retinæ, all the vessels being tortuous and irregularly increased in caliber. Typical

choked disc existed for two years before death, without disturbance of central or peripheral vision. Microscopically all the vessels were densely filled with red corpuscles. The capillaries were of irregular caliber. The canal of Schlemm was of normal size and sparingly filled with red corpuscles. The retinal layers showed edema and pressure changes. Everywhere except in the cornea and retina there were localized collections of small round cells.

Polycythemia megalosplenica. See **Corkscrew vessels.**

Polydacrya. (L.) Excessive lachrymation.

Polydipsic amaurosis. See **Diabetes insipidus, Ocular symptoms of.**

Polygon. A figure possessing many angles.

Polygonoscope. A kaleidoscope in which the angular distance between the mirrors is adjustable.

Polyhedron. A solid bounded by plane faces.

Polymicroscope. (a) A microscope adapted for simultaneous use by several observers. (b) A microscopical peep-show, consisting of a microscope in combination with a series of slides mounted upon an endless chain.

Polymorphic. Polymorphous. Having several or many forms.

Polymyositis, Acute. This painful inflammation of several groups of muscles at one time is said by Schwarz (*En der Augenheilk.*, p. 676) to attack occasionally the extrinsic ocular muscles giving rise to pareses and especially to ptosis.

Polyneuritis, Ocular relations of. See **Neuritis, Multiple**; also the same subhead under **Neurology of the eye.**

Polynucleosis, Ocular relations of. These are quite indirect, but in an interesting but rather vague article by Bérard (*La Clinique Ophtalm.*, Jan., 1916) in which he draws attention, as a part of the study of leukocytosis in general, to the work of Massol, he points out that this writer turned his attention to microbic cultures which, in a medium suitable for their preservation in sufficient vitality, could be absorbed by the intestinal route, since it is in the intestinal tract that one finds the richest and most productive lymphoid organs. "The 'Tapo' cultures which Massol left, when he died, to his pupil and successor, Taponnier, chef du Laboratoire de Sérothérapie, at Geneva, provoked in the intestine an abundant leucocytosis, restored from the time of their administration insufficient polynucleosis, and in all the infections in which we have had occasion to administer them have usually produced most energetic effects."

Polyophthalmia. A human monster characterized by supernumerary eyes.

Polyopia. Polyopsia. Polyopy. The state in which several images of an object are seen at the same time. It is *monocular* or *uniocular* when the polyopia is confined to one eye.

This symptom is generally due to refractive differences in the lens segments which give rise to the formation of separate retinal images. It is not unusual as a sign of beginning cataract. Occasionally the correction of the ametropia masks the polyopic images so that they are not noticed.

A paper on this subject by John C. Bossidy (*Jour. Am. Med. Association*, p. 1030, Sept. 21, 1912) describes a case in a young girl that was probably hysterical. In the discussion A. E. Davis pointed out that monocular diplopia or polyopia, not due to refractive errors or some local condition of the eye, is of rather rare occurrence, and is a phenomenon thus far not satisfactorily explained. The local conditions giving rise to it are the following: (1) most commonly, incipient cataract; (2) irregular astigmatism of the lens, due to spasm of the ciliary muscle, or irregular astigmatism of the cornea, due to corneal opacities; (3) a new-formed or physiologic macula, in cases of squint of long standing following operation of straightening. This condition as a rule lasts but a few days or weeks at the most. The general conditions are (1) hysteria and (2) organic disease of the brain. The local conditions are easily understood, with the exception perhaps of the possibility of a new-formed macula in cases of squint of long standing.

Verhoeff in the endeavor to explain the occurrence of monocular diplopia in such cases, assumed that "there are three centers in the brain almost entirely distinct from each other; one for the binocular perception of relief and two for monocular vision, one of the latter corresponding to the right, and the other to the left eye." See, also, p. 7856, Vol. X of this *Encyclopedia*.

Polyopia monophthalmica. A condition in which an object looked at by one eye gives three or more images.

Polyoptrum. Polyoptron. A multiplying and diminishing lens; a multiplying glass with concaved facets.

Polyopy. Polyopia.

Polyorama. (a) A view of many objects. (b) An optical apparatus presenting many views.

Polyphote. An optical system by which several beams of light are projected in different directions.

Polyprism. A compound prism composed of several prisms of different materials, arranged on a common axis.

Polyscope. Same as diaphanoscope. See p. 3939, Vol. V of this *Encyclopedia*.

Polysinusitis. Inflammation of several sinuses at one time. The ocular relations of this disease as affecting simultaneously the ocular structures and the sinuses about it are fully set forth on p. 1810, Vol. III *et seq.* of this *Encyclopedia.*

A typical case of double polysinusitis with its ocular signs is reported by De Ridder and Jacquet (*Annales d'Ocul.,* p. 127, 1911).

Polystichia. Two or more rows of eyelashes.

Polypus, Ocular. Polyps growing from the ocular structures generally depend from the conjunctiva, lachrymal sac and cornea and have already been described in this *Encyclopedia.* See, in order, p. 3056, Vol. IV; p. 6985, Vol. IX, and p. 3436, Vol. V.

Polyvalent serum. See **Deutschmann's serum.**

Polyzonal lens. Same as Fresnel lens.

Pomatum ophthalmicum. An ointment of 3.8 grammes of calomel, 7.6 each of gray zinc oxide and Armenian bole, and 15 of lard washed in rose-water; used for scrofulous ophthalmia.

Pomegranate, The. *Punica granatum.* Both the blossoms and the fruit of the pomegranate tree were employed by various ancient Greco-Roman physicians in almost all diseases of the eye. Pliny, with characteristic inclination toward the wonderful, declares that if a person, who is wearing neither shoes, girdle, nor ring, plucks a pomegranate blossom with the thumb and fourth finger of the left hand, and then, very gently, touches the flower to his wide-open eyes, then sticks it in his mouth, and, without permitting the teeth to touch it, swallows it, he will be protected against all diseases of the eye for a full year from that very moment.—(T. H. S.)

The bar, stem and root of *Punica granatum* are official in the U. S. P.

For an account of the oculo-toxic symptoms, see **Toxic amblyopia**; also Lewin and Guillery, Vol. II, p. 933, under the caption *Cortex granati.*

Pomeroy, Oren Day. A well-known New York oculist and aurist, inventor of Pomeroy's ear syringe, Pomeroy's aural specula, and many other instruments in almost universal use. He was born at Somers, Conn., of old New England ancestry, Oct. 11, 1834. His liberal education was received at Monson Academy, Mass., and his medical training at Berkshire Medical College, at the Medical Department of the University of the City of New York, and at the College of Physicians and Surgeons of the City of New York. At the last named institution he graduated in 1860.

He settled at once in New York City as ophthalmologist and otologist, and there continued to practise in these specialties until a few years

before his death. He was President of the New York Ophthalmological Society in 1872. He was eye and ear surgeon to the Northern Dispensary, to the New York Foundling Asylum, and surgeon to the Manhattan Eye and Ear Hospital. He was also for a number of years assistant at the Eye and Ear Clinic of the College of Physicians and Surgeons. He wrote a number of journal articles and two or three text books.

He married, in 1865, Hannah M. Miles, daughter of Abial Miles, of New York City. He died of apoplexy, Mar. 20, 1902, at Whitestone, L. I., aged 68.—(T. H. S.)

Pommade de Grandjean. See **Baume ophtalmique jaune,** Vol. II, p. 913 of this *Encyclopedia.*

Pommade de Saint-Yves. Balsamum ophthalmicum yveanum, p. 871, Vol. II of this *Encyclopedia.*

Pommade ophtalmique. An ointment made by triturating together 12 parts each of red mercury oxide and opium, 31 of zinc oxide, and 600 of simple ointment; or by mixing 8 parts of olive-oil and 5 of sulphuric acid, or 3 of oil and 1 part of acid, and washing in warm water until it ceases to color blue litmus; or by mixing 11 parts of sulphuric acid, 4 of oil of mace, and 62 of *onguent nervin.*

Pommade ophtalmique de Guthrie. An ointment of 20 centigrammes of silver nitrate, 400 of lard, and 5 drops of solution of lead subacetate.

Pommade ophtalmique de Velpeau. An ointment of 10 parts of silver nitrate and 800 of lard.

Pomme de vallée. (F.) Datura stramonium.

Pons varolii, Ocular relations of the. This subject is fully discussed as a part of **Brain tumor,** p. 1273, Vol. II; under **Choked disk,** p. 2074, Vol. III and to some extent under **Neurology of the eye.**

It may be added here that a case of *tuberculoma of the pons* reported by A. Noceti (*Archivos d' Optalm.,* Jan., 1912) is worth reading. The patient, a woman of twenty-three years, came on account of paralysis of the left facial and left abducens, with conjugate deviation of the eyes toward the right. With the left eye covered, the right eye retained all normal movements, but with the left eye uncovered the right internal rectus failed to act. There was at this time no involvement of the optic nerve. Nystagmus was present. The patient returned and died of pneumonia two months later. At autopsy a small tumor was seen at the *eminentia teres* of the left side. On microscopic study the following regions were found to be destroyed: The upper half of the median and lateral reticular formations, the central gray substance of the fourth ventricle being entirely lacking; the dorsal longitudinal bundle; the crossed root of the trigeminus; the lateral portion of the

posterior longitudinal bundle; and the dorsal portion of the central bundle. Among the structures pressed upon or displaced were the motor and sensory nuclei of the trigeminus, and its crossed and mesencephalic roots. Numerous tubercle bacilli were demonstrated in the tissues by a special staining method.

Poplar. *Populus alba et nigra.* Poplar juice, in ancient Greco-Roman times, was highly esteemed as a remedy for hypochyma (cataract). The buds, mixed with honey, were also employed, and for almost any and every ophthalmic affection.—(T. H. S.)

Poppy. *Papaver somniferum.* In ancient Greco-Roman times, there were used in ophthalmology what were called "the garden poppy" and also 'the wild poppy." The garden poppy (*papaver sativum*) was, according to Pliny, of two varieties, the white and the black. The white variety was chiefly used in cooking. The black, however, was precisely the modern *papaver somniferum,* and the juice of its stems and the lower portion of its "heads," when expressed and dried, constituted the so-called "poppy-tears," or opium. A less effective preparation was made by boiling the heads and the leaves. This latter product was known as "meconium."

Of the "wild" poppy (we have just been speaking of the "garden" sort) there were three varieties: ceratitis, heraclium, and tithymalum.

The black variety of the garden poppy (*papaver somniferum*) was employed both internally and externally in various diseases of the eye. Internally, of course, it was used for its pain-relieving properties; and, externally, in collyria, because of the same identical (and indestructible) fallacy which forms the basis of its employment in a similar manner today. Sometimes such opium as was intended for use in the form of collyria, was prepared for the purpose by roasting.

Of the wild poppy, the so-called tithymalum was employed as a poultice for epiphora; ceratitis, in veterinary ophthalmology, for corneal affections; while heraclium was used in ocular affections generally.

A number of ancient authors—Diagoras and Pliny in particular—regarded the use of any form of opium in any affection of the eye as reprehensible.—(T. H. S.)

Popular ophthalmology. Domestic ophthalmology. Folklore of ophthalmology. This subject has been to some extent—perhaps sufficiently—treated by Thos. Hall Shastid under **Ophthalmology, History of,** p. 8524, Vol. XI of this *Encyclopedia.* He also draws attention to a number of beliefs, therapeutic and other, that have survived in various localities to our own day. Among these are "putting a razor under the patient's chair to cut the pain in two; rub one eye

to remove a foreign body from the other; dark of the moon, or light of the same to collect 'yarbs' for eye diseases; a flax-seed to chase a foreign body from an eye; for a foreign body, pull down the lower lid of the affected eye, and blow the nose; use the tip of the tongue for removal of foreign bodies; cutting off the mustache often produces eye disease; watching a horse defecate will produce styes in the eyelids of the beholder, unless he crosses the index and middle finger of one hand 'the while that' he watches; however, the extruded feces, will cure these same styes, when applied to them locally; potato poultices are good for this, that and the other eye trouble; a pterygium is actually an insect wing, which has somehow got into an eye and grown tight to it; looking at a hundred dollar bill will cure 'sore eyes'; the eyes, and especially the tears, cannot be frozen; a cataract is something growing 'on' or 'over' an eye; cross-eyes may sometimes be straightened by pulling the 'crown-lock' (by analogy with 'lifting' a 'fallen palate')," etc., etc.

Populus græca. ATHENIAN POPLAR. The buds, boiled in milk, of this plant were formerly used as an external application in caligo corneæ.

Porosis. Chalazion.

Porraceous. Resembling the leek in color; greenish.

Porro prism. Used in the construction of optical instruments. See, e. g., **Corneal microscope, Czapski**'s.

Porta, Giambattista della. This well known physicist was born at Naples in 1538, and died at the same place in 1615. He is said to have been a versatile man, and also kindly, polite and witty. He traveled for years in search of further knowledge, throughout the civilized world. Returning to Naples, he established in his own dwelling a scientific association which he called "The Academy of the Secrets of Nature."

His first book, *"Magia Naturalis,"* contains but little of interest to ophthalmologists. His second work, however, *"De Refractione,"* is truly a memorable volume. The first "book" of this compact little treatise is devoted to the general principles of refraction. The second treats of the burning-glass. In the third, the eye itself is described and enlarged upon, chiefly as an optical instrument. In these three books the author displays but little originality. In the fourth book, however, he adduces original and very striking evidences against the theories of the ancients regarding the nature of light, and in favor of the explanations which, in his day, had recently been expounded. Thus, for example, he declares: "As objects illuminated by the sun send their light through a narrow hole in the window-shutter upon a

paper placed opposite, exactly so does light, pressing through the hole of the pupil, produce images of objects looked at upon the crystalline lens."

The fifth book treats of perspective. In this he commits the curious blunder of declaring that the pupils of the aged are large, of the young, small. His sixth book, which treats of single and double vision, is perhaps the poorest of the work. It is full of errors, and exhibits no originality. Book seven is devoted to entoptic phenomena. In this division of his volume he declares that "the rainbow round a lantern" is not produced, as Aristotle taught, by moisture in the atmosphere, but is formed within the eye. The reasons which he adduces in support of his position are very interesting: (1) The rainbow is always absolutely circular, whatever the shape of the flame. (2) It diminishes in size as we approach the flame, but enlarges as we recede from it. (3) If a person looks at the flame through a small hole in a paper, the rainbow is then observed not around the lantern, but between the eye and the paper. (4) Diseased eyes observe the rainbow, whether the atmosphere be moist or dry. In the eighth book he expounds in excellent fashion (and is the first to do so) the passage of rays of light through three successive media of differing density. The ninth and last book treats in mediocre fashion of rainbows and of color.—(T. H. S.)

Porte-aiguille. (F.) Needle-holder.

Porte-lumière. (F.) An adjustable plane reflector.

Porten, Sally van der. (1819-1875.) A German ophthalmologist who wrote a dissertation on the cataract operation. He also lectured in the Hamburg Medical Society on the pathological anatomy of opacities in the crystalline lens.—(T. H. S.)

Porterfield, William. A celebrated ophthalmologist, whose birth-date and death-date are alike unascertainable.* He was born in Ayrshire, Scotland, of a very respectable family. His early education seems to have been received at Glasgow; his medical degree, however, at Rheims, in 1717. In 1721 he became Fellow of the Royal College of Physicians of Edinburgh, and in 1724 was made professor in the Edinburgh University. He invented a useful "optometer," based on Father Scheiner's experiment, and was the very first to furnish the correct explanation of that proceeding. The word, "optometer," itself, was his invention.

Porterfield wrote:

* All the facts of this sketch are drawn from Hirschberg, who, in turn, has acknowledge his obligations for all the facts relating to Porterfield's life to A. Maitland Ramsay, of Glasgow.

1. Demonstration of the Strength of Bones. (*Edinb. Med. Essays and Observat.*, 1733, 1.)

2. Essay on the Motions of the Eyes. (*Ib.*, 1737, IV.)

3. Treatise on the Eye, the Manner and Phenomena of Vision. (2 vols., Edinb., 1759.)—(T. H. S.)

Porus opticus. See **Disc, Optic.**

Porzio, Simone. An Italian philosopher, who wrote *"De Coloris Oculorum"* (Florence, 1551). Born at Naples in 1497, he was a pupil of Pomponazzi, taught philosophy in Piza, later in Naples, and died in Naples in 1554.—(T. H. S.)

Positional characters. In alphabets and print for the blind (q. v.), this term has been used to designate certain characters which differ only as to their position in the line, upper, lower, or middle. When in the lower or middle position, they have been called *low-level characters.*

Position-finder. A piece of apparatus whereby a gunner can locate, and direct, his sight towards an object not visible to him.

Positive. A view of any object in which the lights and shades correspond with those of the object viewed.

Positive after-images. In which the bright parts of the image correspond to the bright parts of the object, and the dark parts to the dark parts of the object.

Positive complementary after-image. A retinal impression of varying duration and of a complementary color to that of the original object often following rapidly upon an after-image of the same color as the object.

Positive crystals. Uniaxial crystals in which the index of refraction of the extra-ordinary ray is greater than that of the ordinary ray.

Positive distortion. See **Distortion.**

Positive eye-piece. A combination of lenses which intercepts the rays from the objective after they have come to a focus at which micrometric cross-hairs can be adjusted.

Positive focus. See p. 5236, Vol. VII of this *Encyclopedia*.

Positive lens. A convex lens. See also **Ophthalmic lenses and prisms.**

Positive ocular. An eye-piece in which the real image formed by the objective is below the ocular.

Post, Alfred Charles. A noted American surgeon, of considerable importance in ophthalmology. He was born in New York City in 1806, son of Joel H. and Elizabeth Browne Post. He received both his classical and his medical education at Columbia University, taking the medical degree in 1827. After a number of months in London, Paris, Vienna and Berlin, he settled in his native city and was soon success-

ful, especially in ophthalmic and aural surgery. In 1851 he was made professor of surgery at Columbia, and, in this capacity, gave many lectures on the eye. He published, in 1841, a tiny volume "*Observations on the Cure of Strabismus, with an Appendix on a New Operation for the Cure of Stammering.*" This contained a number of excellent colored plates, showing the anatomy of the parts involved, the instruments used, and the methods of employing them. Dr. Post also reported a case of blepharoplasty in 1842, and another in 1878. His skill in the strabismus and cataract operations is said to have been of a high degree. He married, in 1831, Harriett, daughter of Cyrenius Beers, of New York. To the union were born eleven children, one of whom was Dr. George E. Post, a well known medical missionary at Beirut, Syria. Dr. Alfred Charles Post died in 1886.—(T. H. S.)

Posterior baphthalmus. This term was applied by Sulzer and Chappé (*Annales d'Oculistique,* May, 1912; review in *Ophthalmoscope,* June, 1914) to a tumor of the orbit and deep membranes of the eye with the alterations accompanying it. The patient, a girl aged five years, of good personal and family history, was seen on 27th February, 1912, when the mother stated that a defect in her right eye had been noticed for the first time six months previously. On examination, the right eye was found to be proptosed about 1 cm., and displaced downwards and outwards. Its mobility was limited in all directions, and rotation upwards was almost or completely abolished. Its cornea and iris were of normal diameter, but its equatorial diameter was increased, measuring 26 mm. as compared with 20 mm. in the other eye. The intraocular tension was normal. The eye was completely blind, and the pupil was inactive to direct, but active to consensual, stimulation with light. Ophthalmoscopically, there was an almost spherical cyst, two disc-diameters in size, the same color as a normal optic disc, situated at the temporal margin of the disc, and covering its outer four-fifths. The uncovered part of the disc was normal. There was no inflammatory reaction around the cyst, the walls of which were perfectly clear and slightly vascular, while some retinal vessels crossed it. There was nothing in the general condition of the patient to throw any light on the nature of the ocular lesion, and no further information was gained from palpation of the orbit or radiography. The age of the patient contradicted the diagnosis of leukemia, and the absence of pain and inflammatory reaction that of osteo-sarcoma, while the appearance of the tumor differed from that of a glioma. The possibility that the orbital and intra-ocular growths were independent is suggested. The authors seems to lean to the conclusion that the tumor was gliomatous, but fail to offer any explanation of the posterior bapthalmus.

Posterior canthus. In birds, the outer canthus.

Posterior chamber. That portion of the aqueous chamber of the eye that lies behind the iris, and, in the fetus before the seventh month, the pupillary membrane. Except at its periphery it is imaginary, as the iris lies in contact with the capsule of the lens. See the major heading, **Chamber, Posterior.**

Posterior focal distance. The distance between the center of a lens or mirror and its posterior focus.

Posterior iridolysis. See p. 6605, Vol. IX of this *Encyclopedia.*

Posterior lachrymal crest. The vertical ridge upon the outer surface of the lachrymal bone which divides it into two unequal parts, and assists in forming the inner side of the canal for the nasal duct.

Posterior limiting layer of the iris. A layer of radiating elastic fibers (the so-called dilator pupillæ) forming the fourth layer of the iris from before backward.

Posterior ophthalmotomy. Posterior sclerotomy. See p. 5549, Vol. VII of this *Encyclopedia.*

Posterior polar cataract. An opacity of the lens in the form either of centripetal stripes or of circumscribed spots or patches which begin at the posterior pole, just beneath the posterior capsule. It is often a sign of disease of the vitreous, the choroid, or the retina.

Posterior sclerochoroiditis. Posterior staphyloma. This heading is fully discussed and illustrated on p. 3286, Vol. V of this *Encyclopedia et seq.*

The condition is associated usually with high degrees of myopia in which, through stretching, the choroid about the optic papilla becomes atrophic and shows the underlying sclera as a white patch. This choroidal stretching shows itself at first by a slight crescent on the temporal side of the disk, although it is sometimes seen above or below or nasally—and is called a *conus.* The myopic conus must, however, be distinguished from a similar congenital condition which may surround the nerve—*annular conus.*

Posterior sclerosis. See **Tabes**; also **Neurology of the eye,** p. 8357, Vol. XI of this *Encyclopedia.*

Posterior sclerotomy. See p. 5549, Vol. VII of this *Encyclopedia.*

Posterior staphyloma. See **Conus,** p. 3286, Vol. V of this *Encyclopedia.*

Posterior symblepharon. See p. 1096, Vol. II of this *Encyclopedia.*

Posterior synechia. Adhesion of the posterior surface of the iris to the anterior capsule of the lens. See p. 6649, Vol. IX of this *Encyclopedia;* also **Annular pupil,** on p. 496, Vol. I.

Posthia. (L.) Hordeolum.

Post, Martin Hayward. A famous American ophthalmologist. He was

born at St. Louis, Mo., Mar. 31, 1851, the youngest son of the eminent divine, Dr. Truman Marcellus Post, founder and for nearly forty years pastor of the First Congregational Church at St. Louis, and of Frances Henshaw Post. The subject of this sketch received the degree of Bachelor of Arts at Washington University in 1872, as honor man of his class. After a brief period of teaching in the public schools, he proceeded to study medicine at the St. Louis Medical College, where he was graduated in 1877. He was then for a time a student of general

Martin Hayward Post.

surgery with Dr. John T. Hodgen, but later studied ophthalmology with Dr. John Green, with whom he very shortly became associated in practice.

Some years later he studied ophthalmology under Donders, at Utrecht, and under Nettleship, in London. Returning to St. Louis, he continued the association with Dr. John Green, and was soon known as one of the great operators and writers.

Dr. Post was a Fellow of the American College of Surgeons, a Member of the American Academy of Medicine, of the St. Louis Academy of Science, the American Ophthalmological Society, the Medical So-

ciety of City Hospital Alumni, etc. He was recording secretary of the St. Louis Medical Society in 1880 and 1881. He was once chairman of the Ophthalmological Section of the St. Louis Medical Society, and was President of the American Ophthalmological Society at the time of his death. He was an honorary member of the Phi Beta Kappa. He was long a member of the Board of Managers of the Missouri School for the Blind, "being appointed and reappointed by Democratic governors though himself an outspoken Republican in politics."

Dr. Post was an earnest Christian. A member of the Congregational Church, he was regular in attendance, and never suffered to pass unheeded an opportunity to perform his duty as he saw it, or (in the words of Ian Maclaren) "to say a good word for Christ." And he was always stricter with himself than with any others.

The Doctor was twice married: first on May 6, 1885, to Mary Laurence Tyler, of Louisville, Ky., who died Jan. 2, 1888; and, on Jan. 4, 1906, to Mary Brown Tanner, of Jacksonville, Ill., who is yet living. Martin Hayward Post, Jr., ophthalmologist of St. Louis, is his son.

The good and skilful Doctor passed away in Castle Park, Mich., his summer home, whither he had gone in search of health and rest, on the first day of Sept., 1914. The cause of death was angina pectoris.

In personal appearance Dr. Post was large, neither lean nor stout, of a clear and fair complexion, and with brown hair and eyes. He was rather deliberate in his manner, but could, on occasion, be as swift as lightning. Regarding his personal traits in general, however, the following address, by Dr. W. E. Shahan, delivered at a Memorial Service for Dr. Post, at the Missouri School for the Blind, on Mar. 7, 1915, is in itself an excellent summary and is therefore given *in extenso:*

"DR. POST, THE PHYSICIAN

" 'Knowledge comes, but wisdom lingers, and
I linger on the shore;
And the individual withers, and the world
Is more and more.'

"This, a favorite quotation from a favorite poem of Dr. Post's gives some intimate insight into his character as a truly great physician. A raw assistant, viewing for the first time his preparations for an important operation, was often amazed at the apparently trivial questions with which he kept his patient busily engaged. Question about his family, his horses, business, church, politics, anything with

which his mind could be diverted, were actively put to him. Presently, quietly, without emotion, without excitement, the critical stage of the operation would be safely passed. Later in his experience the assistant would begin to perceive that behind a veil of apparently small talk stood the great physician, equipped not only with a high degree of knowledge for the care of his patient's ailments, but, more than that, with wisdom for the care of his patient.

''Such a combination of technical skill, medical knowledge, poise of temperament, and high moral and professional ideal, as characterized Dr. Post is rarely found in any man. Any patient, however poor or friendless, however rich or powerful, consulting him, could feel that he was in absolutely safe hands. He treated all with the same tireless patience, energy, careful skill and sympathy, as he would have treated any member of his own family, giving each of them a part of himself. His best friends were his patients, and felt secure in his care. Those who had the good fortune to be his assistants, look back with pleasure on the profitable years spent with him. He was not only an efficient teacher, but a kindly and sympathetic master. He guided his assistants firmly, piloting them clear of mistakes and blunders, never humiliating them in the presence of his patients, never accentuating his own greatness at the expense of those of less ability or less experience. His assistants and associates always consulted him freely and fully in complete confidence of getting real help in a quiet, but vigorously effective way.

''He was a physician who kept abreast of the times to the day of his death, but he was a man of well balanced judgment, never being carried away by unsubstantial fads and fancies, or over-enthusiastic reports of unusual methods. No patients of his ever suffered as a result of ill-advised experiments. He knew very well that ninety per cent. of all experiments result in failure, and when he adopted a new method of treatment, it was quite certain to be among the ten per cent. that are successful. This accounts partly for the very high average successful results he had in his practice. He was essentially a clinician, culling from the scientific world the best that was in it, and giving his patients the benefit of it.

''He was a physician of unfailing good humor, equipped with a fund of anecdote and gifted with repartee, which he often used in his professional work with scientific accuracy and telling effect. Many a patient in deep gloom over real or imagined disaster has had his gloom dissipated, and his strength saved for better purposes by an aptly put piece of pleasantry or droll bit of absurdity. As an instance, a high school girl in an atmosphere of tragic fear over thoughts of

impending blindness, was suddenly surprised by the question: 'Miss M. how do you pronounce the second day of the week, Toosday or Chuesday?' 'Why,' she said, 'anybody would know it was Toosday.' 'Well,' Dr. Post replied, 'I always thought it was pronounced Monday.' Saying which he left her laughing and thinking that if he could joke like that, perhaps her case was not so bad after all. She is still a useful seeing citizen of Saint Louis.

" 'And the individual withers, and the world is more and more.'

"The good which Dr. Post did in the medical profession did not die with him. His sons, his assistants, associates, and medical friends, have each received a part, and will pass it on to their descendants, and on to the end of time. The great Eye Hospital, which has been put within reach of Washington University, is evidence of his influence among his patients. During his lifetime wealthy patients, at his suggestion, provided funds for putting into hospitals and caring for patients unable to care for themselves. Patients have gone out from this school on such funds. After his death, one of these wealthy people died, and provided in her will for a great eye hospital which will remain as a monument to Dr. Post's initiative, as it will a temple to her philanthropy.

"The life that he lived was straight-forward and upright in all its relations. When his time came to go, he was ready. The heritage he left behind him is a rich one, and 'the world is more and more.' "
—(T. H. S.)

Post-mortem ophthalmoscopy. See **Death, The ophthalmic relations of,** p. 3785, Vol. V of this *Encyclopedia.*

Post-mortem optogram. A retinal photograph persisting after death. See, *supra,* **Legal relations of ophthalmology,** in middle third of article.

Post-mortem or chill cataract. As Maestrini (*Archivio di Ottalmologia,* May, June, 1915) has shown, in certain young animals, the lenses becomes partially opaque after death, and this opacity disappears on raising the temperature. The opacity appears first and remains longest in the central part of the lens. Maestrini found that in some animals in whom this cataract does not appear spontaneously, it is possible to provoke it; on the other hand, it is not possible to provoke it in many species.

Post-ocular. Situated behind the eye or eyes.

Post-ocular neuritis. Inflammation of the optic nerve behind the eye.

Post-operative cataract. See **After-cataract**; also p. 1573, Vol. III of this *Encyclopedia.*

Post-operative complications in eye surgery. This important subject

has been extensively discussed under various sections of this *Encyclopedia,* especially under **After-treatment of ophthalmic operations,** p. 142, Vol. I; as well as **Cataract, Senile,** p. 1712, Vol. III; also in connection with the various operation and other headings, such as **Delirium,** p. 3808, Vol. V.

Speaking of post-operative insanity A. O. Pfingst (*Jour. Ophthal. and Oto-Laryngol.,* June, 1915) believes that it follows operations on the eye more frequently than it does operations on other parts of the body. That the severity of the operation also does not stand in any causative relation with the development of psychoses is evidenced by the frequency of disturbances after operations on the eye, which as a rule are not severe. Pfingst reports two cases of psychoses following cataract operation. The following conclusions are offered:

1. Post-operative insanity does not occur in individuals mentally sound; there is a pre-existing unstable nervous system and the symptoms merely become manifest after the operation—the latter acting as the exciting cause.

2. The cases nearly all occur in senile subjects, and younger subjects with analogous symptoms nearly always have atheromatous blood-vessels or diseased kidneys.

3. The most probable cause of the predisposition lies in an atheromatous condition of the blood vessels and possibly in diseased kidneys with resulting intoxication—hence these cases are more properly senile or toxic (renal) insanities than post-operative or dark-room deliria.

4. All cases of mental aberration associated with hallucinations, etc., even though they be of short duration, may be looked upon as cases of true insanity—differing only in severity and nature of the symptoms.

5. Psychoses may occur after any kind of operation, but that they are especially prone to follow operations upon the genitals and the eyes and more especially cataract operations.

6. Insanity occurs perhaps once in every 400 to 600 cases of surgery, including ophthalmic surgery, and occurs once in about every 200 or 300 cases of cataract extraction.

7. The psychoses following ophthalmic surgery do not differ materially from those after general surgery.

8. Many of the cases are of brief duration, two to four days, but some last months or years, or the patients may even become permanently insane. A small percentage of patients die as a result of the nervous affection.

Post-operative treatment. See **Post-operative complications.**

Postopticus. A name given by Wilder to the posterior pair of the corpora quadrigemina.

Post-orbital. Situated behind the eye or orbit.

Postpolar (posterior polar) cataract. See p. 1572, Vol. III of this *Encyclopedia;* also **Heredity in ophthalmology.**

A remarkable example of the hereditary form of this disease (in which of 64 members of the American Dutill family in four generations, twenty-four had cataract, about equally divided among males and females) is described in a paper by Ziegler and Griscom (*Annals of Ophthalm.*, p. 704, 1916).

Potalia amara. POTALIA RESINIFERA. A smooth shrub of South America, with a bitter, acrid, tonic juice. In Brazil an infusion of the astringent, somewhat mucilaginous leaves is used as a lotion in ophthalmia.

Potassium, Bromide. See **Bromide of potassium,** p. 1312, Vol. II, of this *Encyclopedia.*

Potassium chlorate. KALIUM CHLORICUM, $KClO_3$. Chlorate of potash is found in short, shiny prisms or colorless plates. It is neutral and odorless with a cooling, saline taste. It is permanent in air but decomposes—sometimes with explosive violence—when mixed with some organic matters, such as sugar, cork-dust, tannic acid or with easily oxidizable substances like sulphur or phosphorus.

Although a very old remedy this salt has had comparatively little use in ophthalmic therapy. It is advised by Koster in all forms of conjunctivitis, with or without ulcers at the corneal margin. The drug acts as an astringent and mild antiseptic. Bacteriological investigations show that cultures of various kinds of pathogenic microbes from the mucous secretions of diseased eyes, which developed rapidly on agar-agar, do not grow when a 3 per cent. solution of chlorate of potash is added.

Potassium chloride. KALIUM CHLORATUM VEL CHLORIDUM. SAL DIGESTIVUM SYLVII. This salt forms a double chloride with magnesium in carnallite and is obtained from this mineral in large quantities. It is found in drug stores as whitish, odorless cubes or prisms with the taste of common salt. It freely dissolves in water; sparingly in alcohol.

Chloride of potassium is rarely used in ocular therapy but is of interest to readers of German literature because of the difficulty, partly arising from the confusion of pharmacopeal terminology and partly from the improper use of terms, in determining whether the writer is speaking of potassium chloride, potassium chlorate, potassium perchlorate ($KClO_4$), or chlorinated potassa.

The experimental investigations made by A. Bader (*Zeitschr. f. Augenheilk.*, 33, p. 155, 1915) on the harmless, but stimulating action

of subconjunctival injections of neutral potassium salts on the eyes of rabbits suggested the trial of potassium chloride for therapeutic purposes in chronic diseases of the uvea of the human eye. The writer reports his experiences in six cases, with the following conclusions: Subconjunctival therapeutic injections of from 1 to 2 per cent. solutions of potassium chloride are well tolerated by the eye. They are more painful than the corresponding salt solutions and are advantageously made with an addition of 1 per cent. novocain. Having a more intense action than salt solutions, weaker concentrations and smaller doses suffice for therapeutic stimulation. They favorably influence the diseased tissues of the eye by exerting a local hyperemia, promoting the circulation and thereby bringing about the absorption of intra-ocular inflammatory products, such as opacities of the vitreous, etc. In other words they are a new stimulant, which may be employed as an adjuvant in subconjuncti

Potassium fluoresceinate. See **Fluorescein,** p. 5228, Vol. VII of this *Encyclopedia.*

Potassium hydrate. Potassium hydroxide. Caustic potash. This is a powerful escharotic with a limited use in ophthalmic surgery.

Occasionally it is the cause of ocular burn.

Koerber (*Zeitschrift für Augenheilkunde,* Mar., 1912) reports the case of a man who got a splash of caustic potash into his eye. At first the only symptoms were those of slight conjunctival burn, but after a day or two, severe iridocyclitis, with hypopyon, set in. The writer performed a paracentesis, and after prolonged subsequent treatment, the eye recovered.

Potassium hydroxide has been used for producing cicatricial contraction of the skin in certain forms of entropion. See p. 4338, Vol. VI of this *Encyclopedia.*

Potassium iodide. KI. Iodide of potassium. Occurs in small, colorless, generally translucent, neutral or alkaline cubes. It has a faint odor of iodine and a salty, bitterish taste. It is freely soluble in water and glycerine; less soluble in alcohol.

This important drug has held its own in spite of the many objections urged against its prolonged use, despite the symptoms of iodism set up in persons susceptible to its poisonous action, and notwithstanding the frequent substitution of other remedies for it. After having made trial of many drugs, iodonucleoid, iodalbin, sodium iodide, strontium iodide, mixtures of other iodides, etc., said to exhibit superior virtues yet, on the whole, the Editor has found no iodine prep-

arations equal to this potassic salt for the internal treatment of cases properly calling for its employment. When the full strength of the salt is desired (as it generally is in ocular therapeutics) large doses may, in nineteen instances out of twenty, be given with comfort and safety for several weeks at a time. A good plan is that recommended by Baker. One begins with a fair-sized dose, say 100 minims three times daily, of the following solution: ℞ Potass. iodidi, ℥iii, Aquæ dest. ad. fl ℥vi.

The patient takes the dose with a large quantity—a pint and a half—of water, between meals. He may swallow the dose in a small quantity of water and take his time about drinking the remainder of the diluent; if he can drink 30 ounces of the liquid, all the better. The bowels should be kept open and if the skin can be made to act freely by a bi-weekly Turkish or pilocarpine bath, the less the danger of iodism. Of course the kidneys should be competent and there should be no contraindication to the use of iodides in general. The daily dose can generally be increased 20 to 50 minims, using a minim measure for the purpose, until the patient is taking 300 or 400 grains of the iodide daily. At the end of 2 to 4 weeks intermit the treatment a week or two, as seems desirable. Following this plan one rarely has any serious trouble from intestinal irritation, coryza, dermal eruptions or other toxic symptoms.

As Baker points out, it sometimes happens that large doses will be tolerated when small ones are badly taken. Large doses should not be limited to specific cases, but are indicated in most instances of optic neuritis, ocular paralysis, choroiditis, serous iritis, relapsing iritis, cyclitis, and in interstitial keratitis. They are contra-indicated in gray atrophy of the optic nerve and in most cases of post-neuritic atrophy. Albuminuria is also a contra-indication and the iodide should be cautiously given to children, who do not take it kindly.

It must be remembered that potassic iodide, in common with other iodides, is also used locally, as collyrium and ointment. If they have any action at all it is probably the result of their counter-irritant or stimulating powers. Schmidt-Rimpler advises in certain forms of vitreous opacities the instillation of these eye drops: ℞ Potass. iodidi 0.1 grm. (gr. iss), Aquæ dest. 10.0 c.c. (fʒiiss). In both instances it is often employed to keep other iodides, biniodide of mercury (q. v.) for example, from decomposition and in solution.

Examples of local applications are: ℞ Potass. iodidi, 0.1 gm. (gr. iss), Sodii bicarbonatis, 0.05 gm. (gr. 7-10), Petrolati, 3.0 gm. (gr. xlv). Ft. ungt.

℞ Potass. iodidi, 1.0 gm. (gr. xv), Aquæ dest. 10.0 c.c. (f℥iiss). Both the foregoing are used as stimulating absorbents in corneal opacities.

E. W. Carpenter has used this remedy in subconjunctival injection of four grains to the ounce of distilled water and found it acted very well in severe iridocyclitis. He, also, reports that a one per cent. solution, to be used by the patient in the same way as dionin, acts very satisfactorily.

Potassium oxyquinolinesulphonate. See **Quinosol.**

Potassium permanganate. KALIUM PERMANGANICUM. $KMnO_4$. Permanganate of potash occurs as dark-purple, or nearly black, slender prisms with a metallic lustre. They are odorless but have a sweet, astringent taste. In the presence of most organic matter it is a powerful oxidizing agent. It is freely soluble in water, making an inky solution.

At one time this was a favorite antiseptic in watery solutions of 1 to 2,000 to 500, both as a collyrium and for the treatment of lachrymal diseases, but in recent years it has fallen into general disuse. Possibly its disagreeable and destructive staining qualities and the discovery of numerous other effective germicides have had something to do with this result. In the strength of $\frac{1}{3000}$, three times daily, Kalt recommends it for large flushings of the conjunctival sac in purulent conjunctivitis and corneal ulcer.

J. A. Lippincott employs a $\frac{1}{2000}$ solution in all forms of conjunctivitis associated with the formation of pus.

The best strength for injecting the sac and nasal duct in dacryocystitis is one per cent.

It must not be forgotten that permanganate sprays and douches of the nasal passages are highly recommended as one of the preliminaries to cataract and other major operations of the eye.

Condy's fluid, occasionally used for disinfection of the hands and the sterilizing of instruments, is a solution of sulphate and permanganate of aluminum.

E. Hempel (*Klin. Monatsbl. f. Augenheilk.,* Dec., 1911) describes a case where 1 per cent. potassic permanganate lotion and ½ per cent. silver nitrate drops had been prescribed for an infant with mucopurulent conjunctivitis. By mistake, the parents had used the undiluted solution of permanganate. Both corneæ became grey and opaque, with a striate brown opacity in each. In a few days there was purulent infiltration of both corneæ, and the ultimate result was total leucoma.

It is said that the injurious effects of this salt are due to the potash

liberated when it comes in contact with organic matter. If a few drops of acetic acid be previously added to the solution, this effect is avoided.

Potencies. The older term for homeopathic attenuations. It was, and still is, thought that a dilution made with succussion is better than if merely diluted at once, e. g., that the 3x "potency" is more active therapeutically than a preparation made by diluting one part of tincture with 999 parts of alcohol. Probably the greater efficiency of the potency is due to more thorough and intimate a mixture brought about by the successive steps and smaller quantities handled; but since the day of radio-activity it may be easier to accept the suggestion that the menstruum acquires some of the medicinal properties of the drug, or that by correlation of forces the arrested energy of succussion may contribute to the therapeutic efficiency the "potency." Whatever explanations may be offered, the fact has been observed and corroborated innumerable times for over three quarters of a century that at times the indicated remedy acts better in "potency" than in crude or massive doses.

Fluxion potencies are "high potencies" made by running water or alcohol through an overflowing bottle in which some tincture had been placed. Upon theoretical calculations these were designated, according to the length of time the tap was running, 10,000th, etc., up to the "millionth." But it has been demonstrated that these preparations are no "higher" than the 20th centesimal at best and are not uniform. See **Homeopathy in ophthalmology.**—(J. L. M.)

Pott, Percival. A celebrated London surgeon, probably to be regarded as the inventor of discission as a routine measure for the treatment of soft cataract. He was born in London in 1713, performed most of his operations at St. Bartholomew's Hospital, and died Dec. 22, 1788.

As a general surgeon, he had no equal in his day, and his works on the general subject both were and still are of extreme importance. "Pott's disease" was quite appropriately named for him, and, in fact, our knowledge of the various arthropathies, as well as of hydrocele, hernia, etc., was very much enlarged by this surgical genius. Before his time, discission had indeed been performed for soft cataract. Thus, the procedure is mentioned, first of all, by Celsus, who, however, as well as all succeeding writers, until the 18th century, mentions the operation as a makeshift merely, i. e., to be employed when, after a depression, the lens will not remain on the floor of the vitreous chamber. The quack, Thomas Woolhouse, in 1706, proposed, and may possibly have performed, discission as a regular method of treatment

for soft cataracts. The subject of this sketch, however, in 1772, reported the results of discission as a regular means of treatment for soft cataract, and should, therefore, probably be regarded as its inventor.

Pott wrote, in addition to works and articles of a general character, the following:

1. *Observations of that Disorder of the Corner of the Eye, Commonly Called Fistula Lacrymalis.* (London, 1758, '62, '65, '69, '75; Ger. trans., Dresden, 1771.) Long an authority in many lands it contained, however, but little that was new, and even that little was not of any particular importance.

2. *Chirurgical Observations Relative to the Cataract, the Polypus of the Nose,* etc. (London, 1772.) Contains the description of the discission operation, as a regular performance.—(T. H. S.)

Poudre ophtalmique. (F.) 1. A powder of 300 parts of *Euphrasia officinalis,* 15 of *Armadillo officinalis,* 4 each of mace and cubeb, and 11 of fennel. 2. A powder of from 5 to 12 parts of green vitriol and 140 of sugar, employed to remove spots on the cornea.

Poudre ophtalmique de Beer. See **Collyre sec de Beer.**

Poudre ophtalmique de Boerhaave. (F.) See **Collyre sec de Boerhaave.**

Poultice. CATAPLASM. An application to diseased or painful parts, for the purpose of promoting suppuration, relieving pain, and stimulating or soothing the skin according to circumstances. The linseed-meal poultice is the most easily made, and most satisfactory of all soothing applications. The meal is stirred gradually into a sufficient quantity of boiling water, placed in the bottom of a small basin or teacup, until a perfectly smooth pulp is formed of the proper consistence, and in quantity sufficient to cover completely, to the thickness of ¾ in., the whole painful part. The pulp is then spread on flannel, or poured into a flannel bag, and applied as soon as the heat will permit it to be borne. The bread-and-milk, or even bread and water or bran poultice, is also very good; as is also the oatmeal-porridge poultice, to which a little butter may be added with advantage. If there are foul discharges, charcoal may be used alone, or sprinkled on the surface of the poultice before it is applied; or it may consist of a non-irritating antiseptic lotion (e. g., corrosive sublimate, 1 to 2000). A stimulating poultice may be made by sprinkling oil of turpentine, or chloroform, or mustard in moderate quantity on the surface of any ordinary poultice.—*(Standard Encyclopedia.)*

Pouteau, Claude. A celebrated Lyonese surgeon, who flourished in the middle of the 18th century. Born at Lyons in 1725, he at first studied surgery with his father; later, with Ledran, Morand and J. L. Petit. In 1745 he became chief surgeon to the Hôtel Dieu at Lyons, and died very suddenly in 1775. He was widely known as a tracheotomist and ophthalmologist. An original operation of his was the opening of the lachrymal sac *via* the conjunctiva of the lower lid. Following the incision (which was made between the caruncle and the tarsal cartilage) catgut strings or probes were introduced.—(T. H. S.)

Pouvoir. (F.) Power.

Powder burns of the eye. See p. 1346, Vol. II of this *Encyclopedia;* also under **Injuries of the eye.**

A recent example is reported by Crampton (*Oph. Year-Book,* p. 341, 1916). A man was shot in the face by a blank cartridge from a revolver about two feet distant. Examination immediately after the accident showed severe powder burns of both corneas. The left was perforated in several places as was evident from deposits of carbon on the iris, and the presence of air bubbles and a small amount of blood in the anterior chamber, together with small ragged wounds of the cornea. Apparently but little aqueous was lost. A triangle of exposed conjunctiva was so badly burned that it had to be excised and replaced by a flap of sound conjunctiva. Every effort was made to remove the powder grains from skin, conjunctiva and cornea. Satisfactory recovery took place with good vision. The reaction was not severe and the only signs of infection were a slight iritis and hypopyon of one eye.

Powders for insufflation. Dusting powders. Of the agents especially used in the form of powder for dusting or insufflation, most are antiseptics, astringents and protectives. A few of them are europhen, aristol, dermatol, calomel, formidine, gallanol, gallicin, iodoform, iodol, iodoformogen, lenicet, loretin, calcined magnesia, orthoform, sanoform, sugar, thioform, xeroform and zinol.

F. A. Morrison uses gum arabic as a base for the purpose of insuring prolonged contact of the drug with the eye. For example, in refraction work he employs the following mixture instead of a solution or the gelatine disc: Homatropin. hydrobrom.; cocain. hydrochlor. āā gr. i; pulv. acaciæ gr. v. A little to be placed on the eye-ball, or in the sac, near the outer canthus.

In phlyctenular keratitis Ray H. Dean uses xeroform as a dusting powder not only to the cornea and conjunctiva but on the skin surface of the lids. He also employs it where iodoform powder is usually

required. In the form of dry xeroform gauze applied to the eye with a bandage he finds it of great value as an antiseptic dressing.

Gallicin is used as a dusting powder in many external diseases of the eye, such as the various forms of chronic and subacute conjunctivitis or it may be applied with a camel's-hair pencil to phlyctenules or in superficial ulcer of the cornea. This is the method advised by the editor some years ago, but he would strongly urge the instillation of a couple of drops of holocain (1-5 per cent.) before applying the powder, because it is likely to irritate and cause pain.

Powell, Charles Bertram. A well known ophthalmologist and oto-laryngologist of Bemidji, Minn., born Aug. 22, 1871, in Wabasha County, Minn., the son of Charles and Ann (Hammond) Powell, he received the degree of doctor in medicine at the University of Minnesota in 1894. Settling in Bemidji, he was soon a successful ophthalmologist. He married Mar. 15, 1895, Miss Emma Parmenter. He was a small, lean man, of fair complexion, grey eyes and black hair. He was quiet and deliberate in manner, always even-tempered and courteous, kind and thoughtful of the rights of others. He died Nov. 30, 1914, at his home in Bemidji.—(T. H. S.)

Powell, James W. An early American ophthalmologist, whose life dates are unknown. He published in 1847 an octavo volume of 140 pages, entitled *"The Eye: Its Imperfections and Their Prevention."* The work is a mere compilation, is badly written, and was solely intended to advance the commercial interests of its author. He had been a pupil of Dr. Arthur Jacob, of Dublin, and was a member of the Royal College of Surgeons of Ireland.—(T. H. S.)

Power, Henry. A celebrated English ophthalmologist. Born at Nantes, France, Sept. 3, 1829, he studied at St. Bartholomew's Hospital, and became in 1851 both L. A. A. and M. R. C. S. (Eng.). In 1854 he became F. R. C. S., and one year later received the degree of M. B. (London), winning the gold medal and scholarship in surgery. He was then, at various times, demonstrator of anatomy at the Westminster Hospital, assistant surgeon, surgeon to the Royal Westminster Ophthalmic Hospital, assistant surgeon to the Westminster Hospital, ophthalmic surgeon to St. George's Hospital, and, finally, ophthalmic surgeon to St. Bartholomew's. The last position he held for nearly a quarter of a century. He was an original member of the Ophthalmological Society of the United Kingdom, once a member of its council, twice its vice-president, and for three years its president. He died in his 81st year, Jan. 18, 1911.

Regarding the delightful personality of Henry Power, we quote

the following tributes from two of his intimate friends. Mr. Walter H. Jessop says: "The handsome face with the unclouded brow gave evidence of the happiness and single-heartedness of the man, and encouraged everyone to trust him implicitly. It was an impossibility to imagine his uttering a disparaging word of anyone, and no man was ever more free from enemies. He was an excellent conversationalist and took the keenest interest in everything and everyone. I have never known anyone more quickly grasp and assimilate a subject. This faculty made him a most successful teacher, and as a lecturer he was rarely surpassed. His fine presence, cultivated voice, elegant diction, and clear method of demonstration attracted and kept interested all his hearers. So wedded was he to lecturing that only three months before his death he was giving popular lectures at Whitby."

The following is by Mr. Gustave Hartridge: "As a pupil, colleague, and friend for many years of the late Henry Power, I am glad to place on record my appreciation and admiration of one of the finest characters it has been my privilege to know. Endowed with a handsome presence, a generous and happy disposition, he was beloved by all who came in contact with him.

"No one knows better than I do of Henry Power's many acts of kindness which never saw the light of day; to the poor he was generous to a fault, and at the hospital his hand was frequently in his pocket, though I fear his generosity was sometimes taken advantage of.

"His opinion was eagerly sought and much valued by his colleagues, and by the death of Henry Power ophthalmology lost one of its brightest and best representatives."

Among Power's most important literary works we may mention the following:

1. The sixth, seventh, eighth and ninth editions of Carpenter's *Physiology* (all edited by Power, 1864-1876).

2. *Illustrations of the Principal Diseases of the Eye.* (1869.)

3. Stricker's *"Manual of Human and Comparative Histology."* (Eng. Trans. by Power for New Sydenham Society.)

4. Erb *"On Diseases of the Nervous System."* (Eng. Trans. by Power for v. Ziemssen's Cyclop.)—(T. H. S.)

Power, John Hatch. A celebrated Irish surgeon, who devoted considerable attention to the eye. Born in Dublin Nov. 24, 1806, he became a pupil of Robert Adams, in 1831 Licentiate and in 1844 Fellow of the Royal College of Surgeons of Ireland. In 1835 he was made prosector at the Richmond Hospital School, in 1838 M. D. (Glasgow),

in 1847 surgeon at the Jervis Street Hospital and Fellow of the Council of the Royal College of Surgeons. In 1851 he was appointed professor of anatomy, and in 1861 professor of surgery at the Royal College. His "*Surgical Anatomy of the Arteries*" passed through three editions, and was adopted by the Medical Department of the United States Army as the official guide for surgeons in field and in hospital. Power's only (or chief) ophthalmologic writing was an article in the *Dublin Hospital Gazette,* entitled "On the Structure of the Optic Nerve in Relation to Reversed Retinal Vision." The date of Power's death is not now ascertainable.—(T. H. S.)

Power of a lens. In *optics*, the reciprocal of the focal length of a lens. Thus, if F is the focal length, 1/F, the reciprocal, is equal to the power R of the lens. The power of an ophthalmic lens whose focal length is 1 meter, or 100 cm. is, therefore, $\frac{100}{100} = 1$, the unit of refractive power, called the *dioptry* (q. v.). Similarly, a lens of 20 cm. focal length is $\frac{100}{20} = 5$ dioptries. See also *Dioptry* under **Ophthalmic lenses and prisms.**—(C. F. P.)

Power of vision, Limits of the. See *supra*, **Legal relations of ophthalmology,** in middle third of the section.

Powers, George Hermon. A well known professor of ophthalmology and otology in the University of California. Born June 13, 1840, at Chelsea, Mass., of English ancestry, he received the degree of Bachelor of Arts at Harvard College in 1861, and that of M. D. at the Harvard Medical School in June, 1865. For the next few months he studied with Dr. H. W. Williams, of Boston, and early in the following year settled in San Francisco as ophthalmologist. For many years he taught diseases of the eye, ear, nose and throat at Toland Medical College, and, in fact, continued in this chair after the incorporation of the college with the University of California. According to Dr. Katsuki, of Honolulu, "He was a man of medium height, with gray hair and a gray moustache and the kindest facial expression that I ever saw." Dr. Powers married, in 1872, Cornelia, daughter of Russell Chapman, Esq., of New Haven, Conn. He died in Detroit, Mich., on May 5, 1913.—(T. H. S.)

Præparir-Mikroskop. (G.) Dissecting microscope.

Pragmatagnosia. Inability to recognize objects. See **Blindness,**

Psychic; and Posey and Spiller on *Diseases of the Eye and the Nervous System.*

Pragmatamnesia. See **Blindness, Psychic.** This is a term applied by Wyllie to those patients who have lost the power of calling up in memory the appearance of an object. It differs from pragmatagnosia much as cortical word-blindness differs from pure word-blindness, or as true ocular blindness (from diseases of the brain) differs from cerebral ocular amnesia.

Prasine, Prasinous. Of a yellowish-green color.

Prasoid. Resembling prase, a green-tinted variety of quartz.

Prato's hemioscope. This is one of the numerous modifications of the Fles box (q. v.) or pseudoscope. The mirror has been omitted, but two cylindrical tubes cross from the eye pieces and end in transparent objectives upon which are drawn two different objects. The malingerer is pretty sure to be caught in describing the object which he thinks corresponds to his seeing eye, but that is actually perceived by the pretended amblyopic eye.

Praxinoscope. A form of zætrope or phenakistoscope.

Pray's astigmatic chart. Dr. Pray succeeded very perfectly in overcoming the dazzling and confusion which are generally experienced in looking at large surfaces covered with fine parallel lines. By increasing the number of letters so constructed and drawing them upon an enlarged scale, he produced the well-known and generally approved sheet of letters which bears his name.

Pray's test-types for astigmatism were first published several months after his death, which occurred in 1869. This sheet of types was exhibited at the meeting of the American Ophthalmological Society, in July, 1869, by Dr. H. D. Noyes, of New York, together with the original drawing, in which a letter was cut from each of the twelve sectors. (*Trans. Am. Oph. Soc.*, p. 473, 1878.)

Prayer-beads. See **Abrus precatorius.**

Precautionary examination of eyes of railway and other corporation employees. See **Employees, soldiers and sailors, Examination of the eyes of.**

Precipitins. Antibodies resulting from artificial immunization, with power of precipitating soluble proteid producing the immunization.

Precorneal. Situated on the front of the cornea.

Predisposition to disease. See **Disposition.**

Preequatorial sclerectomy. Schiötz (*Norsk Magazine for Laegevidenskab*, April, 1915, p. 459. Abstract in *Centralblatt f. pr. Aug.*, 40, p. 149), reports on the results of Holth's preequatorial sclerectomy

in 21 cases of detachment of the retina, on dismissal: 5 improved, 9 unchanged, 6 deteriorated. After observation from ¾ to 2½ years after the operation 3 were improved (cured) 5 unchanged, 11 worse, 1 dead, 1 not traceable. In two out of the 3 cured cases the detachment had subsided, in the third according to a letter, V. was better, although still poor, but there was faculty of orientation, which was abolished before operation.

Prefontaine, Louis A. A well known ophthalmologist of Springfield, Mass. Born in 1866, he graduated in medicine at the University of Pennsylvania in 1892, and then for eighteen months was interne in a hospital. He studied ophthalmology at the New York Eye and Ear Infirmary from Jan., 1895, till July, 1896. For the next two years, because of chronic nephritis, he practised in Mexico. Returning to the U. S., he settled at Springfield, Mass., where he was ophthalmologist to Mercy Hospital and Springfield Hospital, and soon became well known as an operator. He died, however, of his chronic ailment, at Springfield, in June, 1905.—(T. H. S.)

Pregnancy, Ocular disturbances in. Disturbances of the sight and disease of the various ocular structures not infrequently arise in the course of pregnancy and during the puerperium. The recognition of such disorders is of the greatest importance because they may be indicative of the gravest dangers either to the life of the woman or to the destruction of her sight.

The visual disturbances may arise suddenly, in the midst of an attack of uremia; or in the course of what is known as "the albuminuria of pregnancy"; from vascular disorders affecting the circulation of portions of the retina as well as of the optic nerve; and as a neuroretinitis, presenting characteristics distinct from those associated with the albuminuria of pregnancy, and, probably, dependent upon the action of compounds generated by the gravid uterus.

The woman may complain of subjective disturbances of vision; of night-blindness, and amaurosis with contraction of field. And, the pregnancy may be accompanied by pigmentation of the lids; the hypersecretion of tears; corneal ulcers; conical cornea; lymphangiectasis; conjunctival hemorrhage; mydriasis; cycloplegia; choroiditis; retinal detachment; retinal hemorrhage; pulsating exophthalmos; retrobulbar neuritis, etc. It must not be forgotten that all forms of eye disease may have been present prior to the pregnancy, and it is equally important to bear in mind that all the ocular structures can become affected during the puerperium. Of most im-

portance are the cases associated with the toxemia of pregnancy; to the details of which this section will be chiefly devoted.

The frequency of such complaints and affections varies: Winckel declared that 1.6 per cent. of pregnant women were subject to ocular disturbances, which disturbances may become manifest at any time during the pregnancy, or not until the weaning of the child. They may appear during the first pregnancy or not until the tenth or twelfth. They may disappear spontaneously after natural labor and leave no sequels, or they may greatly affect the sight and portend such damage that abortion or premature labor should be performed to save sight and life. They may so affect the ocular structures as to set up a gradual destruction of the visual power long after the pregnancy has ended, and the intraocular conditions are likely to become aggravated at each successive pregnancy.

The causes in many cases have been considered to be of reflex origin, but the great majority are dependent upon changes in the circulation, as well as in the blood itself; to auto-intoxication, due to defective metabolism, gastro-intestinal fermentation, defective autotoxic action of the liver, to changes in the secretion of the ductless glands; to the retention and absorption of placental or fetal toxins; to the suppression of the menses; and to an insufficiency of the ovarian secretion.

In pregnancy, as well as in other derangements of the uterus, the eye-lids like other parts of the body are often discolored and pigmented in a very striking manner. The cutaneous surfaces are maculated in various sized, yellowish to blackish mottlings formed by an excessive deposit of the natural pigment of the body in the rete mucosum of the epidermis. Such discolorations are called *chloasmata uterina*. After delivery the maculations gradually fade, but the restoration of the normal color of the skin is usually proportioned to the extent and the depth of the deposit.

Phlyctenular affections of the conjunctiva and cornea are often seen during the course of pregnancy, but as the efflorescences do not exhibit characteristics peculiar to pregnancy, no description of them will be given here. And, only to make mention of it as being sometimes quite annoying, will a note be given of the hypersecretion of tears. The flow of tears may amount to a real epiphora and persist from the third month on to term and be accompanied by salivation. In such cases the lachrymal and salivary glands have been found to be quite swollen.

Conjunctival hemorrhages occur and cause much alarm both be-

cause of their frequency, their spontaneousness and their amount. In recurrent cases inquiry into the state of the woman's cardio-vascular system may detect disease, and in such cases serious changes in health in the later months of pregnancy may arise. Such hemorrhages may be the earliest signs of an approaching virulent toxemia.

Corneal ulcerations have been noted, and, in the enfeebled subjects of the dycrasias, neuroparalytic keratoses develop. Keratoconus has been believed to have arisen in pregnancy and, in certain cases, it has been declared to have had its origin during the distressful period of parturition.

In the latter half of pregnancy a marked degree of weakness of innervation of accommodation has been noted, so that cycloplegia supervenes which may persist for several months. In quite a large number of cases muscular asthenopia is present. If the woman's general condition should become much reduced by nausea and vomiting any muscular asthenopia previously existing would naturally be aggravated. Hysterical symptoms, characterized by an annoying polyopia may develop in the early months which, fortunately, disappears in the later. So, too, strabismus, has been present in and complained of by those whose extraocular muscle-balance has not been good; the management of such cases is most difficult because of the marked irregularity of the manifestations of the strabismus.

The development of cataract has always been attributed to preexisting disease. Disturbances of the mobility of the iris may be purely reflex through the sympathetic system, whereas inflammatory conditions of the iris, ciliary body and choroid are dependent upon either pre-existing causes, intercurrent infections, or toxemias generated by the pregnant state.

By far the most important disturbance of the sight, and it is that disturbance which is most frequently observed, is caused by the retinitis of pregnancy which is accompanied so disastrously by exudation and hemorrhage. Fortunately, it is but a rare occurrence, being found, according to Silex, but once in 3000 to 4000 pregnancies, usually by the middle of the pregnancy, and only exceptionally at an earlier period. According to some observers, it is said to occur most frequently in primiparæ, although Nettleship's series showed that out of 19 cases the retinitis occurred in the fifth, or subsequent pregnancy in 14, while only four occurred in the first, and in two of these, subsequent pregnancies were not accompanied by renal or eye symptoms. Yet cases of optic neuritis occurring in second pregnancies have been met with which ended in blindness. At the other end of

the scale may be mentioned the case of a woman attacked in her tenth pregnancy, who, at the end of her eleventh pregnancy became almost completely blind. Not rarely one finds the first manifestations appearing only several days or weeks after delivery.

Albuminuria during pregnancy is not uncommon, varying from 2 to 20 per cent.; yet frequently albumen may not be found until late. Nevertheless, and it is usually so, the urine is passed in diminished quantity, of a dark color, and, if it contain albumen, shows hyaline, and, rarely, granular casts with fatty degeneration of the epithelial cells.

The nephritis of pregnancy is not a true acute inflammation, because involvement of the vessels is either absent or is quite insignificant, although in certain cases it may be learned that there have been discomforts with edema of the extremities. It is, on the contrary, a fatty degeneration of the tubal epithelium which in favorable cases is rapidly replaced by healthy cells, yet in the less favorable, a chronic nephritis may ensue with unusual rapidity.

The retinitis of pregnancy likewise depends undoubtedly upon that which gives rise to the disturbances in the kidneys, the proximate cause of which is a toxemia which has brought about the disturbance, yet it should be considered as distinct from the ordinary retinitis of nephritis.

While the retinitis of pregnancy is not to be considered to be a form of albuminuric retinitis, in the sense that it is dependent upon the same process which produces an acute nephritis, it must not be overlooked that an ordinary chronic nephritis may have been present before the first pregnancy, nor the further fact, that actual renal retinitis may develop during the course of pregnancy. In these states pregnancy is not a cause, but a complication; Adam found among 935 pregnant women suffering from kidney lesions, 209 cases of retinitis.

The epithelium of the kidneys of the pregnant woman is sensitive to toxins, and it is likely that it is this sensitiveness of the epithelium which causes albuminuria. More pronounced disturbances may cause severe nephritis. The etiology of parenchymatous nephritis may generally be ascribed to bacterial infection, frequently originating in the tonsils. The severe edema that frequently appears early may be regarded as the result of the retention of the chlorids.

A condition of acidosis is usually associated with the toxemia of pregnancy. It is reasonable to suppose that substances in the circulation may affect the liver in a more pronounced way than they affect

the kidneys, yet, because the acidosis may not be distinctly manifest in early and in slight cases, nor be demonstrated in even severe cases of eclampsia, the relationship is not definitely established. Nevertheless, it is a well-established clinical fact that when acidosis is corrected the symptoms are relieved.

It is accepted that the eclampsia of pregnancy is not uremic in origin but is allied to pernicious vomiting which is caused by the circulation of toxic substances in the blood. Violent vomiting, too, may generate conditions which resemble the amblyopia and amaurosis observed after loss of blood. So also amblyopia and amaurosis may arise from excessive hemorrhages during and after labor, which is notably true of hemorrhage in extra-uterine pregnancy as well as during abortion. In cases of repeated abortion may be found diseases of the eye attributable to some general disease, such as syphilis, which disease has acted as the predisposing or exciting cause of the abortion.

Amaurosis with eclampsia, in Rochon-Duvigneaud's report, was present in 17 out of 154 cases. This author believed that a sudden toxic saturation of the optic nerve and retina produced the amaurosis. But retinal changes were not present because they had not had time to develop. His suggestion is supported by the optic atrophy which sometimes follows uremic amaurosis.

The onset of the symptoms is relatively prolonged, the usual symptom is the seeing of only a dark spot when looking at a fixed object. Because of the tendency to a lack of stability of the nervous system in many women during pregnancy the possibilities of an hysterical amaurosis must not be overlooked. Disturbed vision, as for example, polyopia, which increases and then suddenly disappears, may be a manifestation of hysteria, yet hysteria should be the last affection thought of in any case of pregnancy.

Generally the amaurosis is preceded by a decrease in visual acuity and in color vision. No signs of increased intra-cranial pressure are detected, but in 4 per cent. of the cases there are extensive hemorrhages in the choroid and thrombosis of the vessels of the choroid, which thrombosis in many of the smaller vessels produces the degenerative and necrotic changes.

Visual disturbances in pregnancy and in the puerperium, should always suggest the existence of a toxemia and should call for a careful examination of the urine. If the vision is markedly blurred, an ophthalmoscopic examination should be made to determine the existence and extent of the lesions in the retina and optic nerve.

The attacks may last but a few days and the sight be recovered.

In subsequent pregnancies the symptoms may be repeated, in each recurrence with a slight increase in the symptoms with extension, so that decided damage to the retina and optic nerve may result and the vision be reduced, while in others there may be complete blindness from detachment of the retina.

Uremic amaurosis is rarer than the retinitis of pregnancy. It probably is sometimes difficult to ascertain owing to the mental condition of the patient. In cases during pregnancy, there is generally eclampsia, though previous evidences of renal disease may be lacking. Cases of transient puerperal amblyopia with amaurosis in which no statement is given as to the condition of the urine, probably belong to the disease. In 13 cases of eclampsia with nephritis gravidarum, Litzman found the disease 3 times, while Schmorl, in 65 autopsies of eclamptics, noted in 58 thrombi in the smaller cerebral vessels. In this connection it is conceivable that circulatory toxemias might give rise to encephalits becoming localized in the parieto-occipital region or they might produce thrombosis in the visual center or tract.

The ophthalmoscopic signs of the retinitis may not differ from those associated with other forms of nephritis. In general terms there is a widespread neuro-retinitis with exudation and hemorrhage. The retinitis is toxic rather than vascular in origin, although gross endarteritis with obliteration in the choroidal vessels and in the posterior ciliary as well as the retinal vessels have been found. The findings in the majority of cases have been such as to reasonably allow us to suppose that the vascular changes which take place in pregnancy and in the nephritis are of a temporary nature. Perhaps half of the eclamptic cases complain of disturbances of vision, but decidedly few will show evidences of retinitis, and among these the star figures are rarely found.

The prognosis of eye lesions in pregnancy is usually better than in the non-pregnant state, but this depends upon the location of the lesion and whether or not pregnancy is terminated by artificial interruption. Other circumstances being equal, the outlook is more favorable the more suddenly and the more completely blindness occurs during pregnancy.

In the retinitis of pregnancy, the prognosis in so far as it concerns the vision and life of the patient, depends upon the duration of the gestation. If the visual disturbances appear during the first six months, usually the pregnancy should be terminated if the sight is to be saved. It must be borne in mind that any serious eye lesions may be made worse by a subsequent pregnancy. Chronic nephritis

and retinitis caused by it form sufficient indications for the termination of the pregnancy, as the nephritis may get entirely well or at least be greatly improved. The induction of labor, therefore, has been recommended as a therapeutic measure because with the termination of pregnancy the inflammatory deposits may subside and good vision be restored, provided the process has not continued so long that secondary changes have taken place.

As might be expected in so grave a state as that of a complicated pregnancy, authorities differ as to what each considers imperative. By one group of observers, one is advised to induce premature labor in all cases of retinitis, while another counsels the conservative course of artificial termination only when the retinal disease is severe.

In general, it may be said that retinal hemorrhages usually indicate a grave toxemia. If the hemorrhages are over the macula, and if the optic nerve is involved, while the symptoms are not heeded, during which time the toxema becomes increased, a permanent impairment of vision is inevitable. The life, future health and vision of the woman are, therefore, best safeguarded by an interruption of the pregnancy. Usually the vision improves rapidly after delivery, the exudation becomes absorbed and the hemorrhages subside, although in extensive effusions a certain amount of permanent impairment is not uncommon.

The prognosis as regards sight in these cases is probably not so good as is commonly thought, though as regards life it is much better than in the nephritis of the non-pregnant. Sight, however, never improves until the pregnancy is terminated. Without the induction of labor the prognosis is most serious. Cases which go on to term show the largest proportion (15 per cent.), of deaths and the greatest damage to sight. Spontaneous premature delivery shows 11 per cent. of deaths, while after artificial delivery the mortality is but 4 per cent.

Silex found a return to normal vision in but three cases out of thirty-five. Moderate vision, only, therefore, can be anticipated if abortion is induced at the 7th or 8th month of pregnancy. Accordingly, in the last two months, ocular symptoms are to be weighed with other findings. Usually, partial optic atrophy is present with white or pigmented spots at the macula. Fortunately, recovery follows in the majority of the cases in which visual disturbances have not come on until the last two or three weeks.

The ophthalmoscopic examination, when positive, enables one to make an early diagnosis of the underlying condition, which is sometimes otherwise difficult or impossible. A competent ophthalmologist

should be called in consultation, and his decision to terminate the pregnancy should be concurred in. The sight of the mother is of much more importance than the life of the child, that is to say, when the sight is being destroyed by disease caused by the pregnancy, the termination of the pregnancy may check if not cure the disease.

The immediate induction of labor is urged in all cases so soon as retinitis is discovered, on account of both mother and child, since four out of five children die in utero if pregnancy continues. An interval of two years should elapse and complete recovery occur before a fresh pregnancy should be permitted, and, in such event, the patient should be closely watched from conception to delivery.

The albuminuria of pregnancy demands the utmost attention from the family physician, and the question whether premature labor should be induced depends upon the presence or absence of a toxemia, and its degree if present. If, as is usually the case, a toxemia is present, the first indication is to treat this in the usual way of favoring elimination, and the adoption of all means to lower the blood pressure. When ocular symptoms complicate pregnancy, the importance of careful and frequent observation of the blood pressure cannot be too strongly emphasized, for it ranks above urinalysis. A pressure less than 125, may be disregarded; 125-150 needs careful watching and moderate treatment. A pressure of 150, which at the beginning was 100 is more serious than one that was 130 at the start. In such cases only the ophthalmoscope can gauge the effect of the increase of pressure upon the arterioles. A pressure showing 150 needs active treatment, and, if it persists in climbing higher, it will require, in all probability, the induction of premature labor.

The question is indeed most complex, and it is only after weighing all the factors in the case that one should decide whether artificial termination of the pregnancy is or is not necessary. There must always be taken into consideration the facts relating to the nutritive condition of the mother; the objective changes in the fundus and their progress; the social condition of the patient and her family; and the desire of the woman.

Abortion is advised only in the case of eclampsia, while many surgeons believe that where there is progressive failure of vision from retinal changes, premature labor is justified, and abortion should be induced when a previous pregnancy has left the patient with permanent loss of vision. Another holds that marked ocular disturbances and ophthalmoscopic lesions in early pregnancy always demand the evacuation of the uterus. The preservation of the light reflex in the pupillary reactions is regarded by some to be of favorable import.

In some instances there is ample reason for expediting delivery without reference to the involvement of the retina, as in a case seen in consultation by the author, in which in addition to blindness the pregnancy was complicated by uterine fibroids.

A true optic neuritis, that is, papilledema, is not infrequently found associated with the toxemia of pregnancy. In such instances the relations of the optic nerves to the pituitary body must not be overlooked, and because that structure is so frequently affected in the course of pregnancy, it should be borne in mind that pressure on the nerve may arise from swelling of the hypopysis. In a case of retrobulbar neuritis, noticed by Holden, there was at first a trace of edema about the macula soon after premature delivery; recovery ensued, however, but with pigment changes, consisting of thinning of the pigment epithelium in small spots with accumulation in other spots, progressing from the macula to the periphery.

Detachment of the retina is one of the unusual ocular complications of pregnancy and of the puerperium, arising from the strain of prolonged and difficult labor. It occurs more frequently in the course of retinitis of the pregnant than in the retinitis of the non-pregnant. In certain of the cases reported, myopia had already existed, which condition should always be considered as well as the effects of the stress of the puerperium, which stress in the susceptible can be sufficient to cause detachment. Bilateral detachment of the retina has occurred, but, in some fortunate cases, the membranes became re-attached, although optic atrophy supervened. Verderame's case had full restoration after abortion at the 4th month in a fourth pregnancy. From the cases reported, the chances of recovery of perfect vision after detachment of the retina during pregnancy, labor or in the puerperium seem to be better than in the non-puerperal state. The induction of abortion therefore, may favor the re-attachment.

It is well known that distinct modification of the cardio-vascular system occurs during pregnancy, and that the constitution of the blood is changed, comprising an initial reduction followed by increase in amount of fibrous elements; and it is marked by variations in the blood pressure during the last three months. Numerous cases of what have been considered to be embolism of the central artery have been reported, for which affection no other cause than the general blood changes could be assigned. A branch only, as the superior temporal, may become affected, so that only the portions above the macula become ischemic with the consequent defects in the lower

portions of the field and a reduction of the general visual acuity. The value of the cilio-retinal vessels is here fully shown. Occasionally the vision may be greatly regained owing to the restoration of the lumen. In a case of my own full visual acuity was obtained and the field of vision was completely restored. Just as in the non-pregnant obliterative endarteritis may be the cause of the ischemia rather than true embolic foci.

Vitreous hemorrhages frequently occur and are likely to cause great alarm. I recall two cases of extensive subhyaloid hemorrhages in women living in the same village, yet these extravasations were completely absorbed, the one after spontaneous abortion, and the other after full term.

Yellow vision has been met with in connection with the nephritis of the pregnant, which symptom, however, disappeared a few days after the artificial termination of the pregnancy. In this connection should be considered the temporary amauroses associated with cholic jaundice of pregnancy.—(B. C.) See, also, **Gestation**, p. 5371, Vol. VII of this *Encyclopedia*.

The ocular disturbances liable to complicate pregnancy are classed by Woods as: (1) the sudden amaurosis usually called uremic; (2) the retinal changes spoken of as albuminuric retinitis of pregnancy; (3) loss of vision in some parts of the visual field without retinal lesion, sometimes with pallor of the optic disk and (4) neuro-retinitis not resembling that called albuminuric.

From a review of the recent literature he finds that among obstetricians the prevailing opinion is that eclampsia of parturition is not uremic, but, like the pernicious vomiting of pregnancy, results from a toxic substance circulating in the blood. Such a poison can affect the liver in a more characteristic way than the kidneys, and can produce thrombosis in many of the smaller vessels with consequent degenerative and necrotic changes. He quotes Schmorl, who in 58 out of 65 eclamptic autopsies noted thrombi in the smaller cerebral vessels. Woods has seen in a chlorotic girl, appearances nearly identical with those of albuminuric retinitis, clearing up later, but with no albuminuria. He urges that so long as the danger to vision is supposed to be associated exclusively with albuminuria, patients who do not happen to present albuminuria will be permitted to go blind without the essential treatment—termination of the pregnancy. He reports 3 cases in which hemianopsia or other permanent impairment of the field of vision had occurred in association with

the toxemia of pregnancy, one of these patients having been under observation five years. He also refers to somewhat similar cases that have been published by others. Two cases are also reported in which severe hemorrhagic neuro-retinitis occurred associated with the toxemia of pregnancy. In one of these there was very little, and in the other no albumin found in the urine. In both there were the disturbances of excretion that obstetricians now regard as underlying the pernicious vomiting of pregnancy. In one of the cases such vomiting was present, but in the other it was quite absent. In discussing Woods' paper, Bull urged that eclampsia, vomiting, and blindness, must all be regarded as results of an unknown toxic substance circulating in the blood. So long as they were only associated with albuminuria and interstitial nephritis, doctors would run the risk of sacrificing eyes by not insisting on the induction of premature labor. Bull thought that in the cases of obliteration of one-half the field, the lesion was probably a thrombotic process. Pooley urges that in all cases of pregnancy it is not only desirable to examine the urine from time to time, but also to make a routine examination of the eyes with the ophthalmoscope, since a large percentage of patients having lesions of the optic nerve and retina make no complaint of loss of vision, although secondary atrophic changes may lead to complete blindness.

Fejer, discussing the influence of pregnancy and childbirth on diseases of the eyes, raises the question whether some cases of excessive myopia with central chorio-retinitis may not sometimes furnish an indication for the termination of pregnancy. He points out the general agreement as to the injurious influence of disturbed nutrition, altered blood pressure and straining, upon these ocular conditions. But he thinks that every case of the kind must be judged for itself in connection with all related circumstances. He also refers to the danger of retinal detachment, and reports a case of thrombosis of the cavernous sinus following abortion after an attack of influenza. Germane cites 4 cases of corneal disease going on to blindness, and one each of optic neuritis, albuminuric retinitis, soft cataract, and iritis with occlusion of pupil, in all of which he thinks the early termination of pregnancy would have saved the sight. Franklin has briefly discussed the inter-related pathological conditions of the eyes and pelvis.

Retinitis of pregnancy. J. Herbert Fisher (*Proceedings of the Royal Society of Medicine,* July, 1915) makes it clear that he has selected his title deliberately and with care. An ever increasing number of ophthalmic surgeons are taking the later and more en-

lightened view, that it is improper, inexact and unscientific to refer to albuminuric retinitis of pregnancy. The internists and others have for some time urged against this nomenclature. Fisher points out that the attendant nephritis is due to the same cause as the retinitis, that both are therefore the result of a common agent and that agent is most probably a toxic one. The fear is expressed, and not without reason, that the ophthalmic branch of the profession is getting behind the times in reference to its knowledge of general medicine. An interesting quotation is given from Turney, written in 1896, and bearing on the relationship etiologically of such affections as the retinitis of pregnancy, acute yellow atrophy of the liver and renal disease of pregnancy. The latter is stated to be strictly a blood disease.

So far as they occur together retinitis of pregnancy and albuminuria should be disassociated, for it is a patent fact that either may and frequently does exist without the other. Therefore an albumin-free urine need not rule out a diagnosis of toxic retinitis in a pregnant woman.

Eclampsia, which is probably an excessive and fulminant evidence of toxemia, may burst forth without the urine having given any previous warning. Fisher, in a most interesting way, shows the evolution in our views concerning these deplorable conditions accompanying pregnancy. Pathologists and obstetricians being convinced of a toxin or toxins being responsible did not rest at this point, but endeavored to find the nature of the poison. The matter is not settled but progress has been made. At least a name has been attached to the toxins, viz., syncitiotoxins, by which is meant the products of the disintegration of the syncitium cells. These are described as the outer of two layers of cells of fetal origin, which form part of the developing placenta and lie next to the maternal mucosa. They are so named from their immediately connecting the fetal and maternal structures. Their origin and function is physiological, and when their purpose is served their death is likewise. One might say the formation of toxins in one's body is a physiological process. It is not the formation but the failure of proper elimination of toxins which acts deleteriously on the economy. The action of syncitial-toxins is dealt with more fully by Fisher, but does not lend itself well to abstract. Nine case reports are given in full. He finds it difficult to group them. Good recovery of vision is said to be the rule, accompanied by disappearance of all acute manifestations in the retina, differing thereby strikingly from ordinary renal retinitis cases. Some peripherally situated pigment disorder is usual. Permanent defects of vision

appear to depend upon changes in the walls of the retinal arteries or on an atrophic condition of the nerve, which if ascending is probably due to secondary changes in the ganglion cells, the result of imperfect blood supply. The patient may live for many years; a recurrence of the retinitis does not necessarily appear with subsequent pregnancies. In some instances the albumin disappears entirely and in others not. One gathers from Fisher that he does not advise against future pregnancies. A scrutiny of his cases shows that some of the patients died directly of renal troubles, or of conditions secondary thereto. While it is conceivable that a woman may go through subsequent pregnancies without trouble, it seems to the reviewer that it is playing with fire or courting disaster. A woman recovered from the effects of a pregnancy toxemia may have suffered such injury to her excretory organs that a hairline advantage of elimination is maintained. Subsequent pregnancies, while not setting up an acute condition, may so embarrass the excretory organs that the narrow advantage is lost and a chronic interstitial fibrosis is initiated.

Impairment of field from pregnancy. Lagrange reports a case of uremic amaurosis which came on during the seventh month of pregnancy. The patient was delivered at term. When seen eight months later each visual field was contracted to within 10 degrees of the fixation point except downward and a little to the right where it extended to 15 degrees. Central vision, however, was 5/6. The eyegrounds and other parts of the eye appeared normal. Endelman saw a woman who suddenly became blind after delivery. Some vision returned; but there remained complete right and incomplete left homonymous hemianopsia; with amnesic aphasia, alexia, agraphia and visual hallucinations. The pupils and eyeground were normal. The reporter favors the supposition of a toxic encephalitis localized in the parieto-occipital cortex and subcortical substance. A case of left homonymons hemianopsia following profuse hemorrhage with immature labor is reported by Garcia del Mazo. No lesions were visible with the ophthalmoscope. A hemorrhage or thrombosis affecting the visual center or tract is suggested as the cause.

Optic neuritis with pregnancy. From the Tübingen Clinic Weigelin reports 6 cases of impairment of vision from neuritis on post neuritic atrophy, arising in connection with pregnancy. It is most likely to arise in later pregnancies, is favorably influenced by the termination of pregnancy, and recurs with subsequent pregnancies. It was first noticed at the fourth to seventh month. In two of his cases it occurred in the tenth pregnancy. There was improvement

after delivery; but in one of them an additional pregnancy brought almost complete blindness. In another case it was noted in the fourth with relapses during the fifth and sixth pregnancies; but the neuritis was slight and vision afterwards returned almost to normal. In a third case almost complete blindness in the third and fourth pregnancies was followed by relative improvement; but the fifth pregnancy brought amaurosis with optic atrophy. Weigelin ascribes the condition to some toxic influence. Von Reuss saw a case in which there was a distinct temporal hemianopsia, and he suggests that the condition might be due to pressure upon the chiasm through swelling of the hypophysis. In one of his cases almost complete blindness attended the fifteenth and sixteenth pregnancies, occurring within 20 years. Holzbach regards this condition as an interstitial inflammation of the nerve, tending to atrophy and blindness. He finds it to appear before or about the middle of pregnancy, starting as retrobulbar disease. He also notes that it ceases to progress as soon as pregnancy is interrupted, and that if the nerve has not suffered too much the prognosis as to sight is good.

Preiss' stain. By this rapid method excellent preparations of micro-organisms can be made in five minutes. Twenty drops of Giesma solution (see p. 706, Vol. I of this *Encyclopedia*) with distilled water, 10 cc. Divide this into three parts, pour one-third over the preparation and heat it high above the flame until steam appears. Pour off the stain and repeat the process with each of the remaining thirds. Then wash with distilled water.

Prelacrimal (or lachrymal). In front of the lachrymal sac; or bone.

Preliminary capsulotomy. PREPARATORY CAPSULOTOMY. See **Capsulotomy, Preparatory,** p. 1395, Vol. II of this *Encyclopedia.*

Preliminary cystotomy. See **Capsulotomy, Preparatory.**

Preliminary iridectomy. PREPARATORY IRIDECTOMY. See p. 1675, Vol. III of this *Encyclopedia.*

Prenatal eye diseases. See **Intrauterine ocular diseases**; also **Congenital anomalies**; as well as **Heredity in ophthalmology.**

Prentice's astigmatic eye model. See **Teaching methods.**

Pre-ocular. Placed in front of the eye.

Preopticus. Either of the two anterior optic lobes.

Preparation of eye specimens. See the major heading, **Laboratory technique.**

Preparations for ophthalmic operations. These arrangements affect the patient as well as the surgeon and all his assistants. The reader is accordingly referred to such captions as **Cataract, Senile** (p. 1623,

Vol. III *et seq.*, of this *Encyclopedia*) ; **Shock in ophthalmic surgery; Iridectomy; Operative skill** (p. 8491, Vol. XI).: and to the various **Operation** rubrics. As Byers (Wood's *System of Ophth. Operations*, p. 841) points out, the same rules that one follows in the surgery of other parts of the body apply with equal force to the ocular apparatus, and much the same precautions ought to be observed on the part of the surgeon. Especially if he is about to open the eyeball he should himself be clothed and cleansed as if he intended to do a laparotomy. All the well known rules of asepsis and antisepsis should, with slight modifications, be observed in every ophthalmic operation.

As before stated, it is practically impossible to sterilize the eyeball and conjunctival sac, partly because of the favorable nidus for bacterial colonies presented by the retrotarsal folds, the follicles of the conjunctivæ, the lid edges and the lachrymo-nasal tract, and partly because the eye would be injured by antiseptics strong enough to act as effective germicides. It has been found that, on the whole, mechanical lavage or irrigation with mild detergents or indifferent fluids is the best antiseptic measure that can be employed. If we cannot safely kill, by means of powerful agents, the pathogenic bacteria that infest the ocular structures we can at least reduce their numbers, wash away their toxins and lessen their power for harm.

For example, Bach (*Archiv. für Augenheilk.*, 33, 1896) showed, years ago, that by thorough irrigation of the conjunctival sac and lid edges with warm sterile water, weak boric acid, sodium bicarbonate or normal salt solution one obtains not only effective asepsis but the eye, remaining unirritated, is in better form to repel bacterial invasion than if it were disturbed by strong germicides.

In preparation for major operations on the eye, particularly when instruments are introduced into the interior of the globe, as in cataract extraction, iridectomy, iridotomy, etc., it is well to prepare the ocular region the night before the operation. The eyebrow is shaved, the cilia cut off short and the skin about the orbit scrubbed with an ethereal solution of soap and warm water. The lids and lid edges are gently but thoroughly cleansed with cotton soaked in a warm, saturated solution of boric acid, the contents of the lachrymal sac are squeezed out, the lids everted and then, with the retrotarsal folds, irrigated with some mild, warm antiseptic, such as 1:5000 formalin, a 4 per cent. solution of boric acid, or a 1 per cent. salt solution.

Snellen (Graefe-Saemisch *Handbuch, 2te Auflage*), advises washing out the canal and lachrymal sac with Anel's syringe, but one

doubts the expediency or necessity of this procedure except in purulent infection of the tear passages.

Preparation of the patient for ophthalmic operations *involving a skin surface*—the eyelids for example—painting the dermal field of operation with simple tincture of iodine is a ready antiseptic application highly to be commended. It is an effective substitute for other forms of antisepsis, such as washing with ethereal soap-suds, bichloride solutions, White's ointment, etc., although simple cleansing may properly precede the iodine application.

The nearest approach to complete sterilization of the field of operation, with least irritation of the eye structures is attained by the use of an ointment suggested by J. A. White (see **White's ointment**) twenty-four hours before operation. This bichloride mixture may, with advantage, also be used immediately after the operation, as an antiseptic dressing to the wound. The author has never known it to irritate the ocular structures and it disappears by absorption a few hours after its application to the sac, which should be completely filled with it. Draw down the lower lid and apply it on a probe to the lower palpebral conjunctiva, the patient looking up meantime; or, the patient lying down, pour the warm and semi-fluid salve into the lower sac, thus exposed, with a sterile spatula.

A light, sterile, gauze bandage is now applied, not to be removed until half an hour before the operation next day, when the cleansing process should be repeated, the second bandage remaining on the eye until the moment of operation. If the eye now appears unduly hyperemic, or if there is any discharge present, it is well to postpone the operation. Lippincott advises that the nasal cavities, those frequent sources of ocular infection, be sprayed with 1:1000 solution of potassium permanganate on the two dressing occasions just mentioned.

Although the hands of the ophthalmic surgeon do not come into contact with operative wounds to the extent they do in general surgery, yet it is best to avoid even the appearance of evil by careful disinfection. It is well understood that it is almost impossible to destroy all the bacteria and to remove all the toxic matter that lie in the hair follicles, behind the nails and in the dermal folds, but one may serve all practical purposes by simple cleansing of the hands first and the use of disinfectants afterwards.

Wash the hands in the ordinary way for two minutes with green soap and warm water until they seem clean. Douche them under the hot water tap for another minute. Carefully clean the nails and wipe the hands dry with a sterile towel. Now, use a brush with more hot

water and soap and give the hands and nails a thorough scrubbing for three minutes. Dry them again and immerse them in 1:2000 alcoholic solution of sublimate for one minute. Rinse them in sterile water. There are numerous other methods of ante-operative cleansing in vogue but this will be found as effective as any, and the disinfection will be followed by a minimum amount of roughening and cracking of the skin. Should the latter show itself a little "cold cream," or glycerine and gelatine solution will give relief. There are also numerous hand lotions for the purpose.

Some operators, like Allport, wear rubber gloves, but others find that they dull the *tactus eruditus*, which, especially in ophthalmic surgery, is of considerable value to the operator. If used at all they should be very thin and snugly fit the fingers and hand.

As for the gown worn by the ophthalmic surgeon, it should be long enough to descend to the ankles and should be tightly buttoned, pinned or tied at the wrists. It is not necessary for the surgeon to concern himself about the condition of that part of his anatomy that is not exposed and there is no reason why any part of the arm should be naked above the wrist-joint. He should wear a head and mouth covering and he should come to the operating room with as clean clothes and body, and with as calm, cool and collected a state of mind as possible.

Many an awkward moment will be spared that surgeon who mentally marks the steps of the proposed operation in advance of its actual performance, and who personally inspects all the instruments before beginning his work.

J. L. Hayes suggests that four drops of chloroform inhaled by the surgeon with a shaky hand will steady his nerves if taken just before a cataract or other major operation.

Sterilizing of instruments. It is a good habit to boil non-cutting instruments for ten minutes in a sterilizer and then keep them in warm, sterile water during the operation. For disinfection of Graefe knives, keratomes and other delicate instruments the writer still prefers their immersion for 10 to 15 minutes in a 90 per cent. solution of phenol with 10 per cent. glycerine. They are then dipped in 50 per cent. alcohol or sterile water and transferred to the operating dish, which is nearly filled with warm, boiled water. There they remain until used. It is quite certain that boiling needles, small knives, etc., injures their edges and points. Various other methods of disinfection —boiling with soda, immersion in one per cent. formalin mixture in absolute alcohol, etc., have their advocates and are of value. Needles

may be sterilized and kept immersed in sterilized, soft paraffin. Suture materials are kept in various disinfectants and detergents. If of silk the writer prefers the so-called iron-dyed variety prepared with paraffin. It will be found to slip through the tissues with ease, to remain steadily in the eye-hole of the needle and not to become rotten or weak as soon as the ordinary kind.

One cannot praise too highly Boeckmann's dyed catgut sutures. They are of all sizes, may be readily seen in the wound, are strong and do not break or get tangled, and (no small advantage) are absorbed by the tissues so that it is rarely necessary (to do what patients often regard in the light of a second operation) to remove them with scissors and forceps.

Although it is extremely important that instruments should be sterile, it is equally vital to the success of an operation that they be sharp, polished, and free from rust spots or other imperfections. Indeed, it is quite as desirable to be aseptic as antiseptic in our surgical precautions. The contents of the instrument case should be regularly inspected and the cutting instruments tested with a magnifying lens and drum, that any instrument may be repaired, or cleaned, and so made ready for instant use. Place the instruments, after use in an operation, in very hot sterile water, or in a hot solution of sodic carbonate. From this liquid they may be one by one removed, carefully wiped and polished with a soft cloth. The heat of the fluid in which the instrument was recently immersed afterwards serves to complete the drying process and so prevents dulling or rusting of the metallic surface. In a moist climate it may be necessary to preserve all instruments on the loosely arranged shelves of a closed (glass) cabinet in which a 36 candle electric lamp constantly burns.

The position of the patient in operating on the eye. This is important. Some operators prefer the sitting position in an operating chair such as dentists use, but every valuable purpose is generally served by the employment of the ordinary surgeon's table—especially when a general anesthetic is given. A crescentic piece may be cut out of the table, corresponding to the left side of the patient's chest when he is in the prone position. The body of the operator occupies this semilunar space, and he is thus enabled (especially if he is not ambidextrous) to face his patient and manipulate his instruments to greater advantage.

Artificial light is preferable to solar illumination for operations on the eye, because it is always to be depended upon, can be arranged to suit the operator and its brilliancy can be increased or decreased at

will. A covered hand lamp is to be preferred, held and regulated by an assistant. Some operators prefer a head (electric) light or illumination of the field of operation by means of a lens, either stationary or held by an assistant.

Preparatory cystotomy. See **Capsulotomy, Preparatory.**

Preparatory iridectomy. PRELIMINARY IRIDECTOMY. See p. 1675, Vol. III of this *Encyclopedia.*

Preretinal hemorrhage. SUBHYALOID HEMORRHAGES. SEMILUNAR RETINAL HEMORRHAGE. This form of retinal bleeding differs from the ordinary variety in that the blood effusion is not into the substance of the retina but between it and the vitreous. In consequence the retinal tissues suffer no permanent injury from the hemorrhage and after the resorption of the extravasated blood (which is usually poured out around the macula) vision is as good as before the bleeding took place. The treatment consists in complete rest of the individual as well as of his eye, the treatment of the cause of the hemorrhage, if it can be ascertained, and the use of absorbents, especially pilocarpine sweats with large doses of iodides or some substitute for them. See, also, p. 5804, Vol. VIII of this *Encyclopedia.*

In addition to the information given above attention may be drawn to several other sources. Komoto's essay (*Klin. Monatsbl. f. Augenheilk.*, p. 309, 1912) as reviewed by Geo. Coats (*Ophthal. Review,* Aug., 1912) confirms Fisher's observations. At first, exception was taken to the statement by the latter that the extravasation was situated beneath the limitans interna, on the ground that that membrane being formed from the expanded feet of the fibres of Müller, could not be stripped off in the manner described. Further observations, however, have shown that his theoretical objection has no weight, and have fully confirmed the original description. The occurrence of hemorrhage in front of the limitans is extremely exceptional, and seems to occur only when the extravasation is not at the macula, but near the disc.

Komoto reports that in a man aged 17, four days before his death from purpura, radiate and round hemorrhages were present, and in the left eye there was a small hemorrhage at the macula. After death a large dark hemorrhage, measuring 7 mm. by 10 mm., was found at the left macula, as well as some smaller extravasations elsewhere. Microscopically the blood was found to be covered on its vitreous aspect by a thin, homogeneous membrane, directly continuous on both sides with the limitans interna. The retina showed only slight changes—edema, some loosening of the nerve fibre layer, and degeneration of a few nerve fibres. The blood corpuscles had partially

sunk into the lower part of the extravasation. The vitreous was normal. The deeper parts of the cavity were lined with fibrin, and Komoto suggests that the fluidity of the blood in these cases is due to defibrination.

Still earlier Snowball (*Oph. Review,* p. 292, Oct., 1909) gives a complete synopsis of Benedek's paper (Graefe's *Archiv. f. Ophthalm.,* Vol. 70, pt. 2) as well as a concurrent review of E. Klauber's article (in the same journals). It is contended that in collecting such cases it should be noted whether the hemorrhage appears in an otherwise healthy eye, or occurs in a diseased eye, presenting other retinal hemorrhages. The former, or "true" pre-retinal hemorrhages, would only accidentally come to microscopical examination; those of the second class are more commonly met with, and although the appearances that they present are not quite typical, the anatomical conditions, like the ophthalmoscopic, are substantially the same for both groups. v. Benedek here gives a detailed account of the microscopical examination of three eyes with septic retinitis, together with sections from a case of albuminuric retinitis (all belonging therefore to the second group). The publication of these, he thinks, is all the more desirable because in the clinical accounts of cases of this kind views were expressed on the situation of the hemorrhage that did not correspond with actual facts, and this regardless of the exact description of a case that had been given by J. H. Fisher.

In analyzing the various cases that v. Benedek would include under the category of pre-retinal hemorrhage he has found that in ten out of eleven the hemorrhage lay between the membrana limitans interna retinæ and the nerve fibre layer; in only one was it in front of the limitans interna. In 8 cases it was situated in the region of the macula; in 5 of these the blood corpuscles had sunk to the lower part of the hemorrhage—this was a feature peculiar to the macular hemorrhages. In one of his own cases here recorded this result was prevented by the great amount of fibrin present.

Small extravasations of blood are not infrequently found between the membrana limitans interna and the posterior limiting layer of the vitreous in the region of the pre-retinal hemorrhage. Rupture of the former and extension of the hemorrhage between these two layers has been described by J. H. Fisher, and a case recorded by Holmes Spicer showed a similar condition; but in Klauber's cases where this had taken place the blood apparently came from the vessels of the optic disc. The hemorrhage may also pass into the vitreous itself.

The condition of the nerve fibre layer in the area of the hemorrhage is of importance in relation to the anatomy of the retina as well as to the views taken with regard to the anatomical position of the hemorrhages; in all of Klauber's cases the surface of this layer was found rough, due to the fact that the nerve bundles were torn apart and Müller's fibres separated from each other.

Sometimes a layer of new-formed connective tissue encapsules the extravasation of blood; this may so modify the ophthalmoscopic picture that white streaks or patches appear on the surface of the hemorrhage, and a white cicatrix ultimately results.

Detachment of the retina surrounding the hemorrhage may also occur; v. Benedek believes that in his cases this had arisen through the traction which the membrana limitans exerted on the retina as it was pressed forwards by the extravasated blood.

For the differential diagnosis as to the hemorrhage being in front of or behind the membrana limitans interna, it is important to note the presence or absence of reflexes in the form of undulating glistening bands that can often be observed over the surface of the hemorrhage; for although it is true that in both cases the ophthalmoscopic picture may be the same the author cannot conceive how the posterior limiting layer, or hyaloid membrane, of the vitreous can give such a light-reflex as the membrana limitans does. The determination of this point has this practical importance that while a hemorrhage cannot readily break through the membrana limitans it can easily rupture the hyaloid membrane into the vitreous, so that the latter might thereby be injured.

There are, therefore, two groups of pre-retinal hemorrhages which are distinguished by their position relative to the membrana limitans interna; apart from certain differences their clinical picture is on the whole similar, but (according to the results of microscopical examination) the group in which the hemorrhage lies behind this membrane, i. e., is, strictly speaking, still intra-retinal, is the one more commonly met with.

As regards the membranes limiting the retina and vitreous, v. Benedek concludes from the examination of these cases of pre-retinal hemorrhage that in the normal condition the ends of Müller's fibres are adherent to the membrana limitans interna, which again lies next the posterior limiting layer of the vitreous. He will not admit the existence of a margo limitans interna retinæ, as described by Schwalbe, nor does he agree with Wolfrum, who from his embryological studies on the vitreous concluded that the limitans interna has no sharp defini-

tion on the side next the vitreous, and that the latter has no defined outer membrane. He is convinced, however, that the limitans interna is distinct from the vitreous and that there is a definite "posterior limiting layer" of the vitreous, as he calls it; he would discard the term "hyaloid membrane" of the vitreous as confusing. The membrana limitans being an integral part of the retina the hemorrhages occurring behind it might be designated intra-retinal (or marginal) being comparable to those that are found in the deeper layers of the retina and produce no detachment of the limitans.

Pre-retinal hemorrhages occur most frequently at the macula because the limitans is less adherent to Müller's fibres in this region than elsewhere owing, as Spicer has suggested, to the absence of blood-vessels at this part. They probably begin by a rupture of a vessel in the nerve fibre layer, the blood flowing in between the nerve bundles and between them and Müller's fibres and if the hemorrhage still increases the membrana limitans interna becomes detached from the supporting fibres.

Klauber examined two eyes (taken from the same patient) in which "marginal" hemorrhages had been seen intra vitam. The points to which he draws attention are the enormous size of the hemorrhage, the implication of the optic disc, a regular system of folds of detached retina, and the extensive rupture of the blood into the vitreous.

The pre-retinal hemorrhage was situated behind the membrana limitans interna which was ruptured at one part; other extravasations of blood were present within the retina over this area. The limitans interna was continued over the region of the disc as a fine but not very sharply-defined layer composed of fibres of connective tissue, fibrin, and glia elements. The hemorrhages in this case extended over the disc, although usually they end at the edge of the disc because of the firmer attachment of the membrana limitans to the glia and connective tissue of the disc. Klauber concurs with v. Benedek's view that pre-retinal hemorrhages occur as a rule behind the limitans interna, and that the folds of detached retina are due to traction on it by that membrane as it is pressed forward, the hemorrhage being for some reason or other temporarily checked from spreading over the surface. As to the frequency of these hemorrhages at the macula, however, he inclines to Spicer's theory that the limitans interna is less adherent to this part of the retina owing to the absence of blood-vessels, because it was found that in some places this membrane was thinner where a superficial retinal vessel lay nearer it, as if part of it had been left on the wall of the vessel; this adhesion, moreover, would be greater where a plastic inflammation was present in

or around the blood-vessel. The hemorrhage into the vitreous was due to the rupture of the membrana limitans interna by the pressure of the blood from behind.

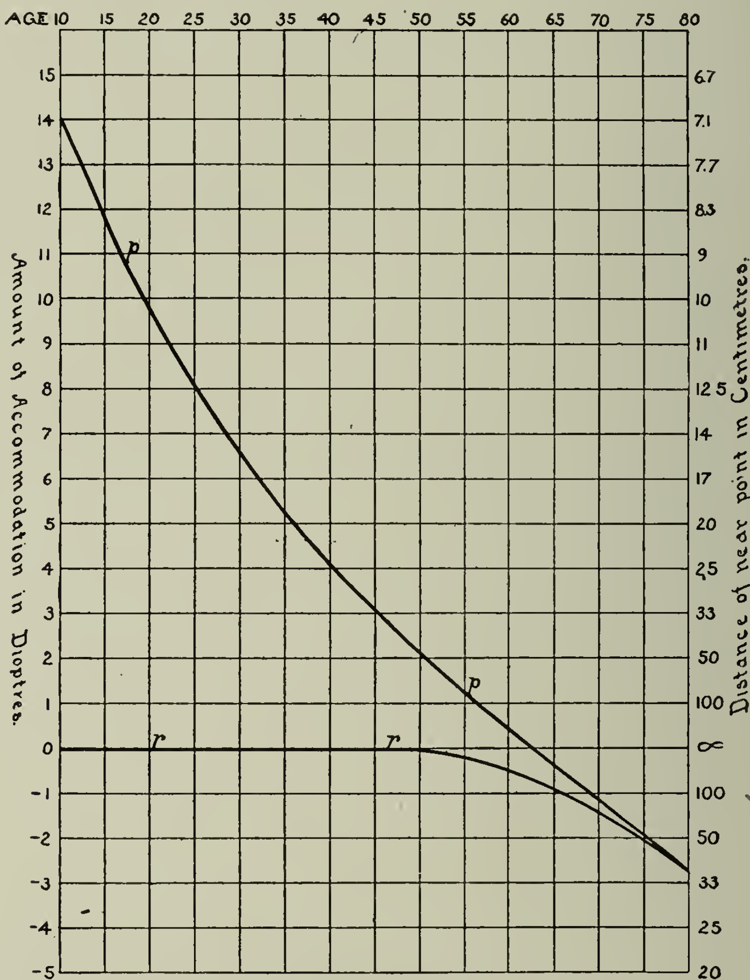
Presbyope. PRESBYTE. A person affected with presbyopia.

Presbyopia.—Presbyopia is the condition of any eye in which, as the result of age, the range of accommodation is diminished and the punctum proximum is removed beyond twenty-two centimetres (eight inches).

Etiology. At birth the lens is soft, elastic, and perfectly transparent, and so nearly of the same index of refraction as the aqueous humor that in children it is often difficult and sometimes is impossible to demonstrate its presence by means of oblique light. It rapidly becomes more dense, especially the nucleus and the parts immediately surrounding it, until, after twenty years of age, it acquires a faint straw-yellow color, even though the lens is transparent, until it has become almost of an amber color, the nucleus increasing at the expense of the cortical substance. The result of this is a diminution in the elasticity; so that, even in early youth, the lens is less capable of swelling and changing its curvature than it was in infancy. However energetic the contraction of the ciliary muscle may be, and however complete the relaxation of the zonula of Zinn, the form of the lens varies less and less under their influence; and, with its convexity, its refraction, during the extreme effort of accommodation, differs less and less from that which it possesses when the eyes are at rest. In other words, the range of accommodation diminishes as age advances. Associated with the progressive increase in the rigidity of the lens there is late in life a weakness or even an atrophy of the ciliary muscle, which is an important factor in the causation of presbyopia.

The range of accommodation diminishes scarcely, if at all, more rapidly from much close work than it does in agriculturists, sailors, and others who, for the most part, look at distant objects. The same is true of the frequent use of the microscope or a magnifying glass as is required in the work of engravers and watchmakers; the regular course of the range of accommodation is maintained despite much or little tension. In eyes predisposed to myopia much near work easily renders them more myopic, but it has no influence on the range of accommodation. There are morbid conditions which cause the range of accommodation, and sometimes also the amount of refraction, to diminish more rapidly than usual: general debility, the result of exhausting diseases, and premature old age.

If a person has quickly and repeatedly to strengthen his glasses, we should suspect the presence of glaucoma. The commencement of cataract also appears to hasten presbyopia, probably through more rapid hardening of the crystalline lens interfering with its mutability of



Range of Accommodation at Various Ages. (Donders.)

form. Paresis or paralysis of accommodation interferes prematurely with the vision of near objects. Any disease that interferes with the nutrition of the lens will eventually limit its power to become more convex during accommodative effort. Also any disease which weakens the ciliary muscle will hasten the advent of presbyopia.

The actual fall of the accommodative power with the age and the range of accommodation for each period of life is very well demonstrated by Donders's diagram (see fig.). The figures on the left give the respective distances for which the eye can be accommodated, those below infinity being so marked as to express the distance at which the convergent rays, for which the eye is adapted in old age, would come to a focus behind its nodal point. The black curved line indicates the actual position of the near point at each time of life, as specified in numbers at the top of the table. The vertical lines joining the near and the far points give the entire range of accommodation. On the left-hand side are the equivalents in dioptres.

It is for emmetropia that this scheme was originally drawn. Hence the line commences at the zero-point of the division. It is straight and coincident with the zero-line until just before reaching the vertical line corresponding with the age 55 years, where it commences to descend and enters the negative portion of the diagram. The position of the punctum remotum does not change until the age of 55 years, when it changes its position and passes from infinity to the rear of the eye. The emmetrope commences to get hypermetropic, the myope notices a decrease in the myopia proportionate with the recession of his near point, and the hypermetrope is conscious of an annoying increase in his hypermetropia. Emmetropia and ametropia, without regard to the degree of the latter are alike subject to the laws governing the range of accommodation.

If we consider presbyopia as commencing when the near point is removed beyond 22 centimetres, which is equal to 4.5 dioptres of positive refraction, then it will be seen by referring to Donders's diagram that myopes of over 7 dioptres can never become presbyopic, for even without accommodation they see at 142 millimetres up to the age of 50 years, and up to the age of 64 by adding to it their dynamic refraction. Even at the age of 80, when there is no longer any dynamic refraction and the static has diminished 2.5 dioptres, they still have remaining $7 - 2.5 = 4.5$ dioptres with which to see at the required distance of 22 centimetres (8 inches). Myopes of lower degree than 7 dioptres become presbyopic, but earlier or later, according to the degree of their myopia.

The emmetrope becomes presbyopic at 40 years of age. The diagram shows that at this age the punctum proximum is at 4.5 dioptres. From this time on, the amount of positive refraction which the eye needs in order to have the requisite 4.5 dioptres must be supplied by convex lenses.

The hypermetrope becomes presbyopic sooner in proportion as his hypermetropia is of higher degree. Thus, a hypermetrope of 4 dioptres is presbyopic at the age of 25 years, because, in order to attain the required 4.5 dioptres of refraction, he must have $4 + 4.5 = 8.5$ dioptres of dynamic refraction, and it is only up to the age of 25 that his accommodation is so strong as that. When the hypermetropia is of higher degree, presbyopia manifests itself still earlier.

Thus it is seen that if we were to restrict the term presbyopia to the position of the uncorrected near point, the meaning of the word would be contradictory, for, as has been shown, the higher the degree of hypermetropia, the earlier in life would the eye become presbyopic, which term must lead to considerable confusion. But the hypermetrope is presbyopic only as soon as, in the use of glasses which neutralize the hypermetropia, the near point lies farther from the eye than 22 centimetres (8 inches).

The following table shows the near point and amplitude of accommodation in dioptres from 10 to 75 years, with 5-year intervals:—

Year	Near Point	Dioptres	Year	Near Point	Dioptres
10.....	7 cm.	14	45.....	28 cm.	3.5
15.....	8.5 cm.	12	50.....	40 cm.	2.5
20.....	10 cm.	10	55.....	55 cm.	1.75
25.....	12 cm.	8.5	60.....	100 cm.	1
30.....	14 cm.	7	65.....	133 cm.	0.75
35.....	18 cm.	5.5	70.....	400 cm.	0.25
40.....	22 cm.	4.5	75.....	....	....

At first, of course, no inconvenience is experienced from this gradual recession of the near point; we do not, in fact, notice it until the distance is so considerable that we cannot easily distinguish small objects. Seldom do we hear that close reading and work cause fatigue. The complaint is rather that vision is not accurate; the letters are not easily distinguished; numbers are confounded; a stroke is seen double. If we place small print in the hand of such a presbyopic person, he begins by holding the book too close to his eye, and does not distinguish; he subsequently very pathognomonically moves the book forward and the head backward, seeks a bright light, complaining of even ordinary print. Often, he may either hold the letters between the light and himself or so place them that a strong light shall fall both on the eye and on the printed page, not so much because the retinal images are by it more strongly illuminated, but because

the pupil contracts; the circles of diffusion thereby become smaller and the retinal images less diffused. Therefore, also, the individual first perceives some difficulty in twilight, unless it be particularly strong. Inconvenience would have arisen even earlier, if the diminution of accommodation had not been accompanied with diminution of the diameter of the pupil. Thus, also, the small pupil of the old man makes the loss of the power of accommodation lighter to him: to this he is indebted for the fact that, even for distances for which he is not accurately accommodated, he still distinguishes tolerably well.

In full daylight in the open air a person can often, even in advanced presbyopia, read ordinary type, and this always succeeds on looking through a small opening.

Presbyopia is indicated by the age of the patient; the position of the near point; history of good distance vision and inability to see near small objects distinctly, being obliged to remove them farther from the eye, or even to seek a bright light, and to hold reading matter at an uncomfortable distance.

Treatment. Having determined from the tests given that the symptoms complained of by the patient are due to a weakening of accommodative power, which prevents the patient using his eyes with comfort for near work at a comfortable distance, this deficiency must be made up by substituting a convex glass of sufficient strength which will enable him to use his eyes with comfort and safety at the necessary distance.

As a rule, in the emmetropic eye the glass necessary to enable the patient to work comfortably at thirty-three centimetres (thirteen inches) will be a + 1 D. spheric lens at the age of 45 years, a + 2 sphere at 50 years of age, a + 2.50 sphere at 55 years, and a + 3 sphere at 60 years or over. This rule, as has been said, is applicable only to the emmetropic eye. Any existing ametropia must first be very carefully sought after and corrected, to which correction the above is added. For example, if there is an hypermetropia of 2 D. at 45 years of age, there should be a + 1 sphere added, which would make the correction a + 3 D. sphere.

All presbyopic hypermetropes should have a glass which represents the sum of the presbyopia and the hypermetropia.

In myopia the amount may be considered the equivalent to a convex glass for the correction of presbyopia; consequently a patient having a myopia of 1 D. would not require any glass for near work until he had reached the age of 50 years, when he would require a + 1 sphere. A myope of 3.5 D. will not require a glass for his presbyopia,

since he will always be able to read at his far point (thirty centimetres). In higher degrees of myopia it will be necessary to weaken the full correction until the patient can see near objects clearly. It will be found impossible to force the patient to read at thirty-three centimetres, because of the reduction of acuity of vision, which compels him to hold print closer to the eye to enable him to see clearly. Frequently high myopes will read more comfortably without any glass, holding the print close and using only one eye at a time.

In simple myopic astigmatism a convex cylinder of a strength equal to the concave cylinder with its axis reversed will enable the patient to read. For instance, if he requires a — 1 cyl. (axis, 180°) for distance, a + 1 cyl. (axis, 90°) will be required for near vision at 45 years of age. At 50 years of age a + 1 sph. ⊃ + 1 cyl. (axis, 90°), and at 60 years of age a + 2 sph. ⊃ + 1 cyl. (axis, 90°) will be necessary.

Compound myopic astigmatism amounting to several dioptres will require a reduction of the spheres only, leaving the cylinder unchanged. In lower degrees of compound myopic astigmatism the combination would be different; for instance, if distance vision required — 0.50 sph. ⊃ — 1 cyl. (axis, 180°) at 45 years of age, he would require — 0.50 sph. ⊃ + 1 cyl. (axis, 90°); at 50 years his requirement would be + 0.50 sph. ⊃ 1 cyl. (axis, 90°).

In mixed astigmatism the combination — 1 sph. ⊃ + 2 cyl. (axis, 90°) for distance will require at 45 years of age + 2 cyl. (axis, 90°); at 50 years, + 1 sph. ⊃ + 2 cyl. (axis, 90°).

It is best to place the distance and near correction in separate frames so that the optical centres of the glasses can be made to correspond to the visual lines when looking at a distance and when using the eyes for near work; otherwise there would be considerable prismatic deviation and distortion of objects produced by the cylindric lenses.

The rule of adding 1, 2, or 3 dioptres to the ametropic correction according to the age of the patient will answer when the patient wishes to use his eyes at thirty-three centimetres, but, as in the case of bookkeepers, musicians, carpenters, and those persons following any occupation in which it will require a longer range, as well as in those in which the object must be held closer, as with the engraver, goldsmith, and embroiderer, the distance at which the work is placed must be ascertained, and a glass should be given whose focal length will be somewhat greater than the distance required.

Great care must be taken not to give too strong a glass for the correction of presbyopia. A strong glass enables the eye to see distinctly

without accommodative effort, but at a distance which makes considerable demand on the convergence. It is better to use the weakest glass that gives the required vision and have the optical centres set a little closer together than the centres of the pupils, the lenses thus acting as weak prisms with their bases inward, thereby diminishing the convergence necessary for binocular fixation, while they lessen the strain on the accommodation and bring the near point closer.—(J. M. B.)

Averages regarding accommodation after middle life are seductive and easy to remember, but, according to Jackson (*Prac. Med. Series;* Eye volume, p. 12, 1908) are really a danger to the clinician.

His paper is based on the records of the refraction and accommodation in 559 patients with vision better than 4/viii. Many illustrative examples are given to show faulty prescription of glasses in patients who have retained an unusual amount of accommodation. The most important practical bearing on the presence of accommodation after middle life is in the false deduction as to the presence and degree of ametropia that may be based on the failure to recognize it. It is really common to meet patients over 50 whose hyperopic astigmatism has been left uncorrected, and the consequent eyestrain unrelieved, because they had enough accommodation to prevent the hyperopia from being absolute.

He concludes that averages should be forgotten in prescribing lenses for an individual patient; that the varitions in accommodation after 50 are as wide between individuals of the same age as between the averages for different ages; that in some persons accommodation persists to extreme old age, and must be taken into account in the correction of presbyopia or the determination of the ametropia present.

Thomson (*Ophthalmic Year-Book,* p. 80, 1912) raises the question whether it is advisable to prescribe presbyopic lenses in just beginning presbyopia, for artisans who can do their ordinary work well enough without such assistance. Whether, in short, it is best to encourage the ciliary muscle to depend upon the assistance of a glass during one period of the twenty-four hours, say for reading at night by artificial light, while obliging it to work without such assistance during the remainder of the day. This question turns upon the permissibility of the workman in a given trade or workship to wear glasses. Where this is permitted, the case may of course be treated in the usual way; where it is not, a point must be stretched in the interest of the patient's livelihood. The same writer raises the further question as to the advice to be given in cases where from the nature

and the degree of the refraction, correcting glasses will have to be worn at an early age. He thinks that in the case of young persons the advice should be to change their occupation if possible. Such advice is gratefully accepted and often acted upon. But where the workman is already well on in his trade and somewhat advanced in life, the matter is very different and a change of occupation is not so easy as a rule.

See, also, the **Accommodation** captions, beginning with p. 48, Vol. I of this *Encyclopedia*, also **Refraction and accommodation.**

Presbyopic. Affected with presbyopia.

Presbytia. Presbyopia.

Prescribing of lenses. In the section **Refraction and accommodation of the eye** this subject will be more thoroughly discussed. For the moment the reader is referred to such captions as **Astigmatism** (p. 656, Vol. I); **Ametropia** (p. 310, Vol. I); **Myopia** (p. 8265, Vol. XI); **Hypermetropia** (p. 6096, Vol. VIII); and in particular **Examination of the eye** (especially p. 4718, Vol. VI) of this *Encyclopedia.*

To the observations made under these rubrics it may be added that success in prescribing lenses depends to some extent (but it is by no means the only consideration) upon determining the amount of myopia, hypermetropia, or astigmatism in the eye or eyes of a patient, and upon the ability to use properly at least two methods of measurement. It is by no means the simple process the optician or the jeweler would have us believe.

Assuming that there is no organic disease of the eye, particularly no opacities in the dioptric media—the cornea, lens and vitreous—the refraction should be first measured objectively, that is, with some instrument like the ophthalmoscope, or, better still, with the skiascope.

Having reached a conclusion, a ''control'' test should be made with test lenses, that is, with such convex and cylindric lenses (and combinations of these) as are found in the test case, that enable the patient to see best in the distance.

The difficulies that present themselves, when an asthenopic patient is to be fitted with glasses, are many. That one may solve these problems with most benefit to the patient not only must the total refractive error be estimated for each eye separately by the foregoing methods, but the condition of the media and fundi, the state of the general health, the balance of the extrinsic eye muscles, the condition of the accommodation, as well as the amount and kind of eye work, must be taken into consideration.

In the same way the surgeon must decide whether a partial or full

correction shall be worn, whether for the distance, for near work, or for both distance and near, or whether two different pairs of glasses (for distance and near) will be required. Will it be wise to keep the ciliary muscle paretic for a time, so that the accommodation is in abeyance while the patient gets accustomed to the new refractive condition induced by the spectacles? Can the patient finally dispense with the lenses ordered, or can he, after wearing them for a time constantly, eventually use them only for reading, writing, etc.?

The improvement of defective vision is, in this country at least, less frequently our object in ordering glasses, than the relief of certain symptoms that have no particular relation to the eyesight. As a matter of fact, we know that most people wear lenses not to enable them to see objects about them more clearly, but to use their eyes without discomfort of some kind.

It is for the relief of eyestrain chiefly that we order glasses and this condition is found more commonly in hyperopia and astigmatism (astigmia) than in myopia. Although the myope cannot, for example, distinguish a friend across the street without his glasses and is obliged to hold his book close to him when he reads he rarely suffers from eyestrain.

Prescription-glass. A spectacle-lens made to prescription.

Preseptal space. The area between the two separate layers of the levator palpebræ superioris (Clermont).

Preservation of eyesight. See **Hygiene of the eye,** p. 6089, Vol. VIII of this *Encyclopedia* and the other references there cited.

Preservation of ocular tissues. See **Laboratory technic,** p. 6886, Vol. IX of this *Encyclopedia*. A few additional formulæ are given in the *Oph. Year-Book*, p. 41, 1909.

For microscopic preparations Petrow places the eyeball from 3 to 5 days in formalin, 80.; potassium acetate, 8.5; potassium nitrate, 4.5; distilled water, 1360. (This is Pick's fluid No. 1, diluted with twice its bulk of water.) After 6 to 12 hours in 70 per cent. alcohol the globe is bisected. It is then placed in potassium acetate, 200; glycerin, 300; distilled water, 900; and left in the thermostat 1 or 2 days, until it sinks to the bottom. Six plates of gelatin are then dissolved in 200 c. c. of the last solution, and after 6 to 12 hours in this it is embedded in gelatin, 250; water, 100; glycerin, 40. Sublimate solution 1 to 2000, 50 c. c., to which 10 or 15 drops of formalin are added.

For the rapid hardening of the eyeball Oatman pierces it with a hollow silver needle, through which fluid is introduced within the eye from a fountain syringe, as rapidly as fluid is withdrawn by the

hardening solution in which it is placed. Through the needle he has introduced formalin 10 per cent., or Zenker's fluid, followed by 95 per cent. alcohol. This method prevents excessive shrinkage of the globe, and hastens the hardening process.

For the preservation of eye specimens Pollock prefers potassium acetate, 90 grammes; glycerin, 180 c. c.; formalin, 20 c. c.; water, 300 c. c. He urges the advantages of paraffin as an embedding material, having relied upon it entirely for the last two and one-half years. It is important not to have the tissue too brittle; and if the examination of the lens is not essential, Pollock picks out the nucleus with the point of a sharp knife before making the section. Disturbance of the section after cutting is largely a matter of technique. To remove the paraffin, the section is placed for about three minutes in a tube of xylol. The section can be kept indefinitely between layers of paper on microscopical slide trays. As a hardening solution Pollock has given up 5 per cent. formalin, preferring the following: mercuric chlorid 1:100 and saturated solution of picric acid, each 44 parts; glacial acetic acid 10, formalin 2 parts. It remains in this fluid 24 hours, and then through alcohol, increasing strength from 30 to 95 per cent. For clearing the sections Pollock prefers cedar-wood oil, xylol rendering them too brittle. The oil must be thoroughly removed by soaking in paraffin 12 to 24 hours. The paraffin used should have as low a melting point as possible, from above 45 centigrade to above 52, according to the temperature of the air.

To obtain serial sections of eyes embedded in celloidin, Calderaro hardens the mass with slow evaporation of ether, under a bell glass with an open flask of chloroform. Every three or four hours the block is carefully dried of the chloroform deposited on it. After two days the chloroform is removed, and in three or four days the block has become almost horny in hardness. To obtain regular thin sections the surface is smeared with a syrupy solution of celloidin, which is allowed to dry one-half to one minute before the next section is cut. Neither the knife nor the block of celloidin should be dipped into alcohol.

Presmyopia. A term employed by J. A. Hess. See Donders' *Refraction and Accommodation of the Eye*, p. 329.

Pressione intraoculare. (It.) Intraocular pressure or tension.

Pressure, Blood. This subject in its relations to ophthalmology has been briefly discussed on p. 1227, Vol. II, of this *Encyclopedia*. Recently a large amount of literature has appeared dealing mostly with

increased arterial tension and the incidence of glaucoma, cataract, intraocular changes in the vessels, etc.

In 26 out of 30 cases of primary glaucoma E. Fricker (*Prac. Med. Series; Eye,* p. 106, 1913) noted considerably increased arterial blood-pressure, above 150 mm., according to von Recklinghausen's scale. The frequency of arteriosclerosis, alone or combined with affections of the heart, kidneys and lungs, was striking. With the exception of one case of tabes, other diseases were entirely lacking. The frequency of arteriosclerosis in glaucoma has been known for a long time and considered as a disturbance of circulation leading to an augmented supply of blood during systole and an insufficient efflux during diastole. Thus a permanent dilatation of the capillaries and a tendency to increased transudation results, and if there is an impediment in the outflow of the ocular fluids, the intra-ocular tension rises. In the complicated pathogenesis of glaucoma there are, besides local predisposition, perhaps several elements which we do not know. The diseases of the cardiovascular and renal systems, and extensive impediment of respiration as in emphysema, with increased blood-pressure as an accompanying symptom, undoubtedly are in a genetic connection with glaucoma and cannot be regarded as accidental findings. Therefore in no case of glaucoma an exact general examination, with measuring the blood-pressure, ought to be omitted. It should also be considered in the treatment, by venesection, elimination of factors apt to increase the blood-pressure, by suitable diet and way of living. Cardiac stimulants and vasotonics might be injurious in cases of increased blood-pressure.

It is generally conceded that the symptoms marking the onset of congestive glaucoma, are due to a circulatory disturbance, leading to an increase of blood-pressure, which, in connection with local arteriosclerosis and vasomotor fluctuations, causes a rise in the capillary pressure, venous stasis and increased transudation. Craggs and Taylor (*Oph. Year-Book,* p. 169, 1913) examined the systemic blood-pressure and the intraocular tension in 225 subjects in India, and conclude that high arterial tension is not a necessary, and apparently not even a leading, factor in the etiology of glaucoma. Though a high arterial tension may sometimes be a powerful causative factor in the production of an attack of glaucoma, it is still very far from having to be reckoned with as a widely prevalent influence.

Alexandre has investigated the relationship that arterial tension and viscosity of the blood bear to the increase of intra-ocular tension. His conclusions are that inflammatory glaucoma is independent of

arterial tension, that chronic simple glaucoma, though often occurring in patients with high arterial tension, is not dependent on arterial sclerosis, and that patients with hemorrhagic glaucoma show a marked hydremia, together with high arterial tension. This explains the tendency to hemorrhages. A knowledge of the relationship borne by the increase in arterial tension, and the hydremia of the blood, to the high intra-ocular tension should suggest the employment at an early stage of a suitable medicinal regimen. Terson protests against the use of the term "inflammatory"; he agrees with Alexandre that acute or subacute congestive glaucoma occurs independently of high arterial tension; in chronic simple glaucoma the tension is nearly always high, whilst in hemorrhagic glaucoma it is invariably so; he considers that in order to clear up various points, experiments should be undertaken on apes. Alexandre's most valuable results are in his opinion those which concern the viscosity of the blood; Terson has for many years taught and practiced that arterial tension should be reduced not only before glaucoma operations, but also before those for cataract.

Every increase or decrease in blood pressure probably results in a corresponding temporary alteration in the ocular pressure. This temporary change is quickly compensated for by a reciprocal alteration in lymph excretion, so that the volume of the ocular contents remains fairly constant. The intraocular fluids are the result of an osmotic process through the ciliary processes. There are no lymphatics in the eye and the iris and vitreous have no secretory function.

Permanently increased tension is not due to high blood pressure directly, but may co-exist with it only in the absence of adequate compensation. Five cases are reported in proof of this by Ibershoff (*Jour. Ophth. Otol. and Larg.*, Feb., 1913). High blood pressure in a person having a small cornea or a large lens predisposes to glaucoma. It requires but an agency to upset the balance of secretion and excretion. This writer thinks that sudden lowering of the ocular tension by opening the eyeball, subjects the eye to the danger of hemorrhage; consequently, blood pressure should be lowered first.

He further holds that senile cataract is due to an osmotic unbalance, the vitreous and aqueous being either hypertonic or hypotonic to the lens. He thinks the presence of an increased amount of sugar in the ocular fluids in diabetes may explain the frequency of cataract in such subjects. In the presence of increased blood pressure the ocular fluids have a higher specific gravity and he thinks these fluids being hypertonic to the lens causes it to shrink and become opaque. The author is of the opinion that further studies along this line will show that the

regulation of blood pressure will prove a valuable method of non-operative treatment of glaucoma and cataract.

R. H. Elliott (*Ophthalmoscope*, p. 327, July, 1915), thus concludes his extensive observations on intraocular pressure and tension: (1) It is essential to bear in mind, that in dealing with the physical conditions governing the behavior of the intra-ocular fluid, as it passes into and out of the eye, we have to do with a body of moving water, and that the laws to which we must appeal are those of hydro-dynamics, and not those of hydro-statics.

(2) The question whether the intra-ocular fluid is poured out by an act of secretion, or by a process of pressure filtration, is still *sub judice*. Probably the action is a combined one, pressure and secretory activity each taking a part therein. Fortunately, the interest involved is academic, rather than practical.

(3) The systemic blood pressure tends, as it rises and falls, to exert a corresponding influence upon the intra-ocular blood pressure. This influence may, however, be masked or even counteracted by the action of a number of other factors.

(4) The venous exit pressure throughout the eye is probably always a little in excess of the intra-ocular pressure.

(5) Whilst admitting that there are difficulties on all hands, the most probable explanation of the method by which the intra-ocular fluid finds its way into the canal of Schlemm and into the iris veins, is that the action is osmotic in nature.

L. Casolino (*Archivio di Ottalmologia*, p. 588, 1914) in an attempt to estimate the effect of certain drugs on the arterial tension used on dogs hydrochloride of cholin and nitrite of amyl as depressors of the arterial tension; and hydrochloride of adrenalin, strophanthin and neutral sulphate of atropin as hypertensive agents. He found that 0.02 g. of cholin produced lowering of the arterial and of the endocular pressure. Twice the amount named of cholin caused lowering of the arterial tension, whereas in the ocular pressure there was at first a rise and later a diminution. Nitrite of amyl by inhalation caused slight lowering of the arterial and very marked lowering of the endocular pressnre. After cutting the cervical vagi, inhalation of the drug caused a considerable lowering of the arterial pressure. Adrenalin constantly produced a rise of both arterial and endocular pressure, the latter ephemeral in character. Stimulation of the vagus after injection of atropine caused an increase in the arterial and lowering of the endocular pressure. Strophanthus caused an increase in the arterial and lowering of the endocular pressure. Stimulation

of the vagus with a weak induced current caused a considerable lowering of both pressures. Stimulation of the crural, on the other hand, caused a rise in both pressures.

Among other interesting articles on the subject of the ocular relations of blood-pressure are contributions by Alex. MacRae (*Ophthalmoscope,* p. 168, April, 1915) ; Mark Schonberg (*Oph. Sec. Am. Med. Assocn.,* June, 1913), as well as a report of the discussion on the *physiology of intraocular pressure* at the Royal Society of Medicine (*Ophthal. Review,* p. 51, Feb., 1913).

Prester John. From *Belul Gian,* meaning "precious stone." A fabulous king (or race of kings) of Ethiopia or Abyssinia. Sometimes the term would seem to apply to a single individual; again to be merely a royal title, like the Egyptian "Pharaoh." The first account of Prester John appears in the chronicle, or chronicles, of Otho, or Otto, Bishop of Friesingen, in 1156. He is also mentioned by Marco Polo, Bishop Jordanus, Maimonides (who calls him "Preste-Cuan"), by Mandeville, and by numerous other writers.

Ariosto, in his "*Orlando Furioso,*" depicts him as totally blind. He also says that Prester, or Presbyter, John, though the richest man in all the world, suffered terribly from hunger (*cf.* Phineus), because of harpies which were continually carrying away his food.

The people of Prester John's country were also interesting ophthalmologically. They had each (according to a letter to the Emperor Connenus written by Prester John himself) but one eye, which, in some of them, was placed in the center of the forehead, while, in others, it was situated in the back of the head.—(T. H. S.)

Pretended blindness. PRETENDED AMBLYOPIA. See **Blindness, Simulation of.**

Prevention of blindness. See the references to captions in this *Encyclopedia* under **Hygiene of the eye**; in particular p. 1138, Vol. II.

Preyer, Thierry William. A well known Anglo-German physician, of a slight ophthalmic importance because of his "Farben- und Temperatursinn" (1881). Born at Moss-Side (near Manchester) England, July 4, 1841, he received his general education at London, Duisburg and Bonn. He then studied medicine at Bonn, Berlin, Vienna, Heidelberg and Paris. His Ph. D. was received in 1862, his M. D. in 1866. In 1869 he was full professor of physiology at Jena. In 1888 he removed to Berlin, where he was privatdocent in physiology till 1893. He died July 15, 1897.—(T. H. S.)

Price's cyclo-phorometer. See **Phorometer.**

Prichard, Augustin. A famous Bristol ophthalmologist, the first to

propose enucleation of an injured eye for the prevention of sympathetic ophthalmia, and the inventor of numerous ophthalmic instruments still in use. He was born at Bristol, the second son of Dr. James Cowles Prichard, a famous ethnologist, in 1818. From 1834 to '39 he served as surgeon's apprentice to his uncle, Mr. J. B. Estlin, founder of the Bristol Eye Dispensary. He also studied at the British Medical School and Infirmary, and at St. Bartholemew's Hospital, London. He received the degrees of M. R. C. S. (Eng.) and L. S. A. in 1840. In 1840 and '41 he studied at Berlin, receiving the degree M. D. For a year he studied ophthalmology at Vienna and Paris.

Returning to England in 1842, he settled in Bristol, was shortly appointed lecturer on surgery and anatomy, and, in 1849, was elected surgeon to the Infirmary. In this same year he received the F. R. C. S. Eng. At the end of twenty years he was obliged to resign his surgeoncy at the Infirmary, because of a regulation of the institution. He continued, however, in private practice for many years, and had an international reputation as an operator.

Dr. Prichard was a founder of the Bristol Medico-Chirurgical Society, and for many years was surgeon to Clifton College. At two of the annual meetings of the British Medical Association he delivered the address on surgery. In 1893 he retired from practice.

In 1845 he married Mary Sibellah, a daughter of the Rev. Thomas Ley. To the union were born four sons and three daughters. Mrs. Prichard died in 1893, aged 74.

On Dec. 20, 1898, Dr. Prichard became afflicted with intestinal obstruction. An operation was at once performed, and it seems to have been successful; but, not long afterward, because of his great age, the Doctor passed from life, Jan. 5, 1899.

Dr. Prichard's chief claim to remembrance will eventually rest upon his reputation as an operator. Concerning his skill in this regard, a number of stories are told, no doubt all of them true. Thus, a writer in the *British Medical Journal*, Jan. 22, 1898 says: "Mr. Prichard always used [in the cataract operation] a Beer's triangular knife, and never employed a speculum or caught hold of the conjunctiva with a forceps, and he operated without any anesthetic. In this operation, as in all others which he undertook, he exhibited great dexterity."

In person Dr. Prichard was very impressive, being tall, handsome, and dignified. He was a rigid disciplinarian. He was, however, something of a joker among his friends. He was also a man of varied

interests, being one of the earliest pioneers in the art of photography —a hobby at which he worked even till the year of his death. He was also an excellent draughtsman, and "left a large collection of water-color drawings of the old city, subjects in which he took a great interest." His Christmas presents, in fact, were almost always sketches or water-colors produced by his own hand. He was a good man, public spirited, of very great kindness to the poor, and was loved by all who knew him.—(T. H. S.)

Prickly heat of the lids. See **Eyelids, Miliaria of the.**

Priestley, Joseph (1733-1804). Born in Fieldhead, near Leeds, England. In 1755 he became minister to a small congregation at Needham Market, in Suffolk. In 1758 he quitted Needham for Nantwich; and in 1761 he removed, as teacher of languages and belles lettres, to an academy at Warrington. At this time he published a *History of Electric Science* (1767). In the same year he removed to Leeds, having been appointed minister of the Mill Hill dissenting chapel there. The fact of a brewery being beside his dwelling gave a new direction to his energetic and versatile mind; he began to study chemistry, and in 1774 made his epoch-making discovery of oxygen. In 1780 he became minister of a dissenting chapel at Birmingham. In 1791 he was elected to a charge at Hackney; but his honestly-avowed opinions had made him unpopular, and he (1794) came to America, where he was heartily received. Priestley's theological views were far in advance of his time. His chemical work on gases was of the highest value. He invented the pneumatic trough, and was the first to apply carbon dioxid in "aërating" waters. *(Standard Encyclopedia.)*

Primärablenkung des Auges. (G.) Primary deviation of the eye.

Primary capsulotomy. See **Capsulotomy, Preparatory.**

Primary cataract. Primitive cataract. A cataract which is developed without any known connection with other diseases of the eye.

Primary colors. Colors that can not be resolved into two or more other colors: of Newton, red, orange, yellow, green, blue, indigo, and violet; of Wollaston, red, green, blue, and violet; of Brewster, red, yellow, and blue; of modern oculists, red, green, and violet.

Primary deviation of the eye. The deviation of the originally squinting eye in a case of strabismus.

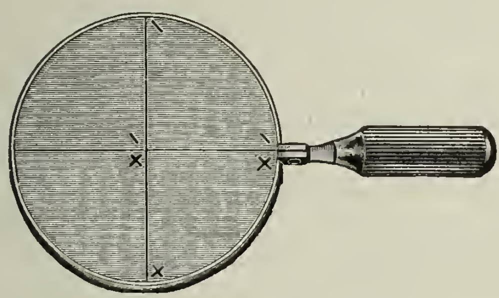
Primary focus. Principal focus. The point at which parallel rays falling on a lens or mirror are collected, or toward which they tend to converge. In the case of a spherical mirror the principal focus is at a distance of one half the radius of curvature from the centre of the mirror; in the case of a spherical lens it is situated at the centre

of curvature. The principal focus of a concave lens or of a convex mirror is virtual; of a convex lens or concave mirror, real. According to the laws of conjugate foci, rays emanating from the principal focus are reflected or refracted in parallel directions.—(Foster.)

Primaverile catarro. (It.) Spring catarrh or vernal conjunctivitis.

Primitive cataract. A cataract which is developed without any known connection with other disease of the eye.

Prince's combination lens. This useful little device is made with 2 spheres and 2 cylinders + and — of one focus, 0.12 or 0.25. It is intended as a control test by means of which one-eighth or one-quarter



Prince's Combination Lens.

dioptre spherical or cylinder may be added or subtracted rapidly from the combination already before the patient's eye.

Prince, The. The name by which Avicenna was most commonly known among the Arabians. His real name was Abu Ali al-Husain b. Abdallah b. al Husain b. Ali as-Saih arrais Ibn Sina. See **Avicenna.** —(T. H. S.)

Principal axis. The line passing through the centre of a lens or a mirror and the centre of curvature of the surface of which the lenticular or specular surface is a segment.

Principal focal length. See **Focus.**

Principal focal line. See **Focal.**

Principal focus. See **Focus.**

Principle of recurrence. In alphabets and print for the blind (q. v.), the letters of the alphabet recur in literature with very unequal frequency. In any selection containing 10,000 letters, *e* would probably recur more than 1,000 times, while *z* would recur less than 20 times. It is evident that by assigning the most desirable characters to the most common letters, an advantage is gained: This principle may be used to economize space or dots.

Principal plane of a crystal. A plane perpendicular to the parallel surfaces of a crystal, and passing through the *axis* or any *parallel line.* See also **Axis** and **Polarization.**

Principal planes. Two planes so situated with respect to a compound lens system that the effect of the system is equivalent to that of an infinitely thin lens which receives light whilst in one of these planes and is suddenly transferred to the other before the emergence of the light. See, also, **Cardinal points of a lens.**

Principal point. See **Cardinal points of a lens.**

Principal posterior focus. That point posterior to the dioptric media of the eye at which rays impinging upon the cornea in a direction parallel to the optic axis are united. In emmetropic eyes the principal focus is upon the retina; in myopic eyes, in front of it; in hypermetropic eyes, behind it.

Principal ray. The ray which passes perpendicularly from the eye to the picture.

Principal section. Any plane passing through the optical axis.

Print. As Hermann Cohn (*Encyklopädie der Augenheilk.,* p. 152) and many others have pointed out, complaints about poor print are several centuries old. These complaints and the correction of the defects in the printed pages that make for easy reading are treated of in a number of rubrics of this *Encyclopedia.* See, e. g., p. 1421, Vol. II; also under **Hygiene of the eye,** as well as under **Blindness, Prevention of,** and **School children, Eyes of.**

Prism. In *optics,* any refracting medium bounded by two plane surfaces that include an angle between them. The inclination of the surfaces or faces to one another is called the *apex-angle,* or *refracting angle.* The edge of the prism is the line in which the two surfaces meet, or would meet, if produced; and the plane which is perpendicular to the faces and edge of the prism is called the principal section. The base is the side opposite to the apex-angle. See **Lenses and prisms, Ophthalmic,** p. 7212, Vol. X (and succeeding captions) of this *Encyclopedia.*

Prismatic. Separated or distributed by an optical prism; refracted by a prism.

Prismatically. By means of, or in the form or manner of, a prism.

Prismatic colors. The colors into which a ray of light on passing through a prism is decomposed.

Prismatic compass. An optical apparatus such that an object on the horizon can be sighted through a pair of vanes at the same time that the alignment of a magnetic compass needle is read off.

Prismatic focus. The point to which all the rays emanating from one point of an object are projected by a prism. In general, the distance of this focus from the prism is different from that of the object, but in the position of minimum deviation of the prism it is the same.

Prismatic lens. A lens with one or more concave or lenticular surfaces.

Prismatoid. A solid terminated by two parallel polygons connected by triangular faces.

Prism batteries. See p. 4691, Vol. VI of this *Encyclopedia.*

Prism chart, Cogan's. See p. 2013, Vol. III of this *Encyclopedia.*

Prism-convergence. See p. 4692, Vol. VI of this *Encyclopedia;* also **Muscles, Ocular.**

Prism, Creté's. See p. 3559, Vol. V of this *Encyclopedia.*

Prism creuse. (F.) Hollow prism.

Prism-dioptry. Prism diopter. In *optics,* a standard tangent deflection of a bundle of parallel rays of light produced by a prism. It is equal to one centimeter on a tangent-plane placed at a distance of one meter *behind* the prism. To practically measure this deflection while looking through a prism or lens, and consequently upon a tangent-plane placed *in front* of the prism, it is necessary to multiply both the meter and the centimeter by six, in order to insure parallel incidence of the rays constituting the beam of light. The prism-dioptry establishes a definite relation between the refractive powers of prisms and lenses, since the prism-dioptries in decentered lenses are in direct proportion to their refractive powers and *decentration* (q. v.). The prism-dioptry also bears a unique relation to the *meter-angle* (q. v.), and establishes a dimensional unit at the optic commissure—as made manifest in heterophoria by the distance between the retinal image-centers projected to the *chiasmal-image* (q. v.) for both eyes—that is equal to one-hundredth part of the distance between the nodal point and the retina in the eye whose deviation corresponds to one prism-dioptry. The sign used to designate the prism-dioptry is a triangle. Thus the unit, 1^{Δ}, of the dioptral system is distinguished from $1°$ of the old degree system. Since 1895 American lens manufacturers have adopted the prism-dioptry as the standard unit of prismatic power. (Prentice, *Archives of Ophthalmology,* Vol. XIX, Nos. 1 and 2, 1890, and *Ophthalmic Record,* January, 1914.)—(C. F. P.) See, also, p. 7275, Vol. X, of this *Encyclopedia.*

Prism-divergence. The power of abduction as tested by prisms. See **Examination of the eye.**

Prism, Double. A name given to the Maddox and similar devices—two prisms with their bases together, one of the means of detecting and measuring oculomuscular defects. See p. 8070, Vol. XI; and p. 4685, Vol. VI of this *Encyclopedia.*

Prism duction. See **Muscles, Ocular.**

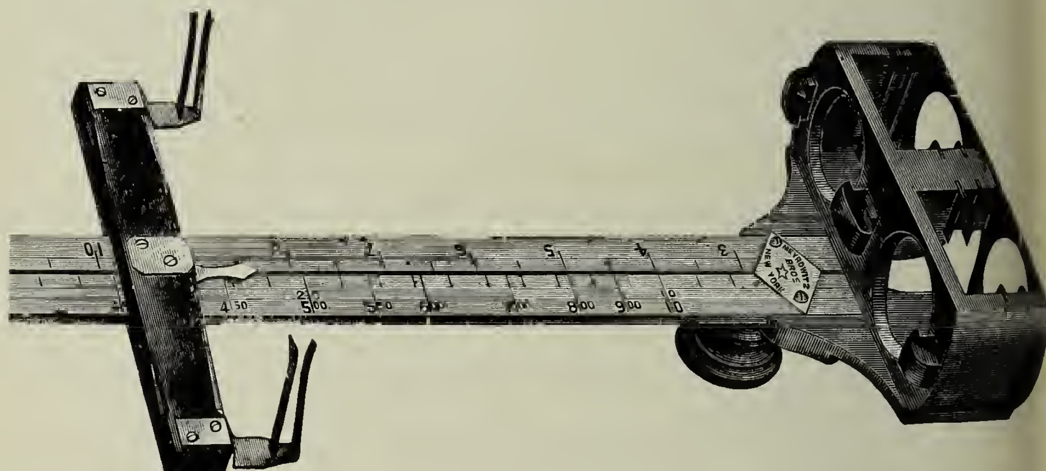
Prismenwinkel. (G.) Angle of a prism.

Prisme redresseur. (F.) Image-reversing prism.

Prismes croisśes. (F.) Crossed prisms.

Prism holder. See p. 4687, Vol. VI of this *Encyclopedia.*

A good example of this device is the prism holder of Noyes (see the cut) arranged for testing and exercising the power of the ocular muscles at close range, for investigating binocular vision, etc. There



Noyes' Prism Holder.

are cells for lenses and prisms, and the device is usually provided with a series of test cards.

Prism, Landolt. The Herschel prism with Landolt's graduation affords a means of finding quickly and without trouble the angle of strabismus of an eye and the degree of convergence.

The little instrument contains two prisms having two similar refracting angles and coupled in such a manner that, as one is made to revolve, the other rotates at the same rate but in the opposite direction. This produces a continuously variable prismatic deflection in one direction, the pencil of rays being deflected in a plane at right angles to the handle. The prisms are rotated by means of a milled ring which bears the graduations, motion being imparted to it by the thumb or index finger of the hand holding the instrument. On the opposite

side to the graduated face the instrument has a revolving vulcanite cup which fits snugly the rim of the orbital cavity so as to give the instrument an immovable position in front of the eye. The cup is so arranged that it will accommodate a green glass or a Maddox cylinder, the object of the former being to mask the dispersion at large angles of deviation.

The milled ring carries in front two graduations. Of these the upper one, which is read by the upper index, shows the deviation in degrees produced by the two prisms. The zero point of the scale is marked by the nickel-plated screw. The zero point serves also to indicate the position of the base. This is always situated at right angles to the handle and always on the side of the zero point of the upper scale, as indicated by the nickel-plated screw.

Herschel Prism with Landolt's Graduation.

If, for example, the deviation in any given case be found to be 5° a prism of 5° may be prescribed for either eye since the angle is about twice as great as the angle of deviation.

The lower scale, as devised by Prof. Landolt, reads the deviation in terms of metre-radians. Since these depend upon the magnitude of the basal line the scale is so arranged that the metre-radians can be read off for various basal lines. At the bottom edge will be found the metre-radian for a basal line of 58 mm. the first ring reads the values for 60 mm, the second ring for 62 mm, the third ring for 64 mm, and the inner edge those for 67 mm. Readings are taken by the long index. If, for example, with a basal line of 58 mm the reading shows a deficiency of 3 metre-radians it will be 2.9 metre-radians for a basal line of 60 mm, 2.8 metre-radians for 62 mm, 2.7 metre-radians for 64 mm, and 2.5 metre-radians for a basal line of 67 mm.

The symbols — L and — R indicate the nature of the deviation of the squinting eye, they show accordingly whether the strabismus is divergent or convergent.

When the prisms are held in front of the right eye and the images brought to coincidence when a reading is taken on the side bearing the symbol — R this shows that the squint is divergent and in this case the base occupies a nasal position. If a reading be taken for the right eye on the side bearing the symbol — L the squint is convergent and the base of the correcting prism occupies accordingly a temporal position. The symbol — L corresponds therefore to + R and, conversely, — R corresponds to + L.

When using the prisms in front of the trial frame it is best to remove the vulcanite eye cup.

Prism, Liquid. See **Liquid prism.**

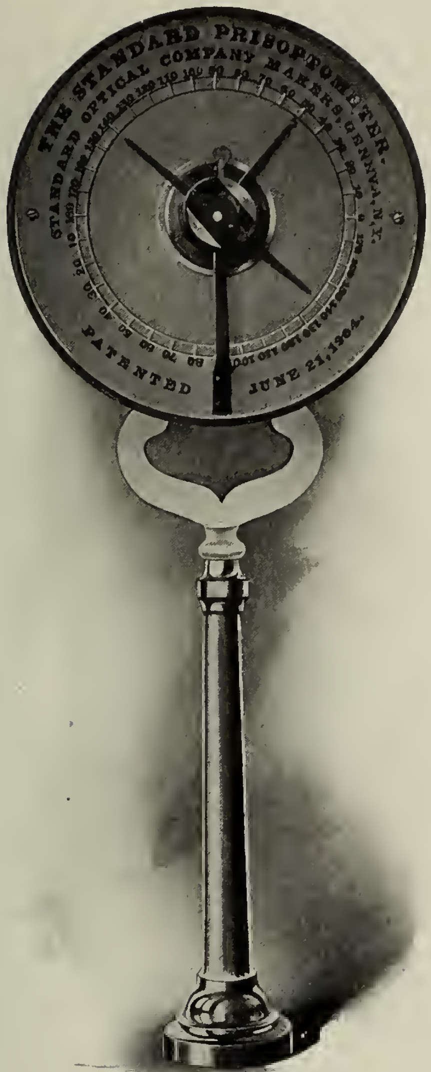
Prism, Maddox. Two prisms with their bases together; used in testing for torsion of the eyeball. See **Examination of the eye**; as well as **Muscles, Ocular.**

Prism measure, Geneva. In this patented device (see cut) the position

Geneva Prism Measure.

of the index figure, F, will be governed by the difference of the thickness of the lens at the points D D′, and the degree of the prism will be indicated on scale E by the pointer F.

Prism, Nicol. Two slabs of Iceland spar cemented together and deflecting a ray of light in such a way that it is split in two, one part being totally reflected and the other (polarized ray) passing through.



Prisoptometer.

Prismoid. A body approaching the form of a prism.

Prismoidal. Having or relating to a prismoid.

Prismoid, Liquid. Watery; prismoid. A term applied by J. Thomson to the "refracting watery liquid in the entrant corner between the lip of the eyelid and the cornea."

Prismometer. Instrument for determining the strength of prisms. See **Prism measure**; also **Charts, Prism**, p. 2016, Vol. III of this *Encyclopedia.*

Prismometer, Prentice's. See **Teaching methods.**

Prismoptometer. Prisoptometer. An instrument for testing the refraction of the eye by means of a revolving prism. See **Prisoptometer.**

Prismo-sphere. A lens between whose surfaces a prism is incorporated, in order to deflect the focus of the lens from the axis; a *sphero-prismatic lens.* See **Lenses and prisms, Ophthalmic.**

Prisoptometer. An instrument devised by Culbertson (*N. Y. Med. Jour.*, p. 366, 1886) for determining ametropia. It is composed of a single glass prism, the apex of which covers half of a central opening in a diaphragm which can be revolved at pleasure. The eye of the patient looks through the aperture at a white circle 20 feet distant. The prism is fixed at such a distance that the margins of the true and false images induced by it are tangent in the emmetropic eye. In myopia the circles lap, in hypermetropia they separate. A lens which makes the circles tangent denotes the glass required by the eye. Astigmatism is detected by revolving the prism disc.

The "Improved" prisoptometer is a trade name given to the instrument depicted in the text. The proprieters describe it as follows: The dial is graduated around the full circle, and the pointers can be revolved continuously, or reversed, as desired. A series of cells in front of the dial will carry such lenses as are needed to obtain a full correction. The back of the dial is fitted with a hood, similar to the hood of a steroscope, which shuts out side-light, allows the patient to see clearly with both eyes open, and holds the head and eye steadily in position. See cut on preceding page.

Prism, Risley's. A prism which rotates in a metal frame marked with a scale: used in testing ocular muscles for imbalance. See p. 4692, Vol. VI of this *Encyclopedia.*

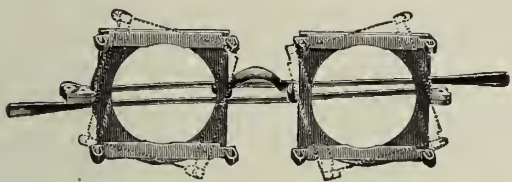
Prisms. See **Lenses and prisms, Ophthalmic.**

Prisms, Decentration of. See **Lenses and prisms, Ophthalmic.**

Prisms, Exercises with. See **Muscles, Ocular.**

Prisms for correction of heterophoria. See **Muscles, Ocular.**

Prisms, Frame for square. See p. 4690, Vol. VI of this *Encyclopedia*. See, also, the illustration herewith.



Frame for Square Prisms with Revolving Cell.

Prisms in asthenopia. In addition to what is said on this subject under **Muscles, Ocular,** it may be added that A. S. Green (*California State Jour. Med.*, November, 1912) has found in dealing with refraction cases, that the following methods have been satisfactory:

1. In hyperopia with esophoria for distance and near, give a full correction of the refractive error, to be worn constantly. This will relieve the strain on the ciliary muscles and internal recti.

2. In hyperopia with orthophoria for distance, and 3 degrees to 4 degrees of exophoria near, an under correction of the hyperopia will usually suffice.

3. In hyperopia with orthophoria for distance, but 6 degrees to 10 degrees exophoria for near, give a partial correction of the hyperopia, combined with 1 degree to 3 degree prism base in over each eye, for near use only. The interni in such a case need the prisms at the near point, but would not tolerate them for distance.

4. In hyperopia with 6 degrees to 8 degrees of exophoria for distance and 10 degrees to 12 degrees near, give a partial refractive correction combined with a 1 degree to 3 degrees prism base in over each eye for constant wear.

5. In hyperopia with esophoria combined with hyperphoria, the correction of the refractive error will frequently correct the muscle imbalance.

6. In hyperopia with exophoria combined with a hyperphoria, it will usually be necessary to correct a part of the hyperphoria as well as a part of the exophoria.

7. In myopia with exophoria, give the full refractive correction. This may have to be modified in an adult who has never worn glasses, so as to avoid retinal fatigue.

8. In myopia with esophoria, an under correction of the refractive error with decentration of the lenses will be indicated.

These rules are only general, and variations will have to be made

in individual cases, as to the strength of the focal corrections and prisms. Where the refractive correction will allow, it is better to decenter a lens rather than order a prism. Lenses are now made allowing a decentration of 5 to 6 mm. Decentering a 1 D lens 10 mm. gives a prism of 1 degree, so that in the stronger lenses it is often easy to obtain the desired prismatic correction by decentration. It is well to see that the patient does not get an undesired prismatic effect due to faulty adjustment of the glasses. One frequently sees glasses with their optical centers too wide or too narrow, with a consequent eye strain. This is quickly relieved in many cases by a proper adjustment of the frames.

In conclusion, it may be well to call attention to the correction of presbyopia. Along with the failure of the accommodation, we frequently have a weakened convergence. The internal recti, as well as other muscles of the body, undergo senile atrophy, which is, strictly speaking, a physiological process. In such cases, if the lenses are decentered in, the patient will often be more comfortable.

Prisms in heterophoria. See **Prisms in asthenopia.**

Prisms, Numeration of. See p. 7275, Vol. X; also p. 8390, Vol. XI of this *Encyclopedia.*

Prisms, Ophthalmic. See **Lenses and prisms, Ophthalmic.**

Prism-spherometer. A prism for ascertaining the curvature of a spherical surface.

Prism-tests. See **Muscles, Ocular,** as well as **Examination of the eye.**

Prism-train. A series of dioptric prisms.

Prism verger. A trade name for a prism device similar in construction to the well-known Stevens phorometer. See the illustration.

The name of this instrument as well as the following description and remarks as to its various applications is taken from E. E. Maddox' article in the *Ophthalmic Review,* April, 1907. The verger consists of a spectacle frame, fitted with a rotating prism before each eye, and was proposed and figured in the first edition of his book on *"Prisms,"* in 1889, but difficulties at the time prevented its manufacture.

It may be regarded as the complement of the phorometer which it slightly resembles in principle, though differing in purpose. In the phorometer both prisms rotate in the same sense, whereas in this they rotate in opposite senses. The phorometer measures heterophoria, which this instrument, used alone, cannot. On the other hand, the phorometer will not measure vergence power, or train the ocular innervations for both of which this is intended.

It consists of a frame in which two prisms, each of 6° deviation, are so mounted as to be simultaneously rotated in opposite senses, by

turning a milled head. One prism is permanently attached to the toothed disc which bears it, but the other can be slipped out of its fitting and be reintroduced the reverse way. The object of this is to make the instrument available not only for horizontal vergence, but also for vertical.

With regard to vergence, it is only necessary to consider its four cardinal varieties, i. e., convergence, divergence, supravergence and infravergence. Vergence relates to the bearing of the visual axes with reference to each other, not to their parallel movements. In speaking of supravergence and infravergence, it is necessary to specify to which eye the word belongs. As a generic term, however, we may speak of "vertical vergence," to avoid reference to one eye more than another; and in so speaking we assume supravergence of one eye to be necessarily equal to infravergence of the other. In all non-paralytic cases this assumption is correct.

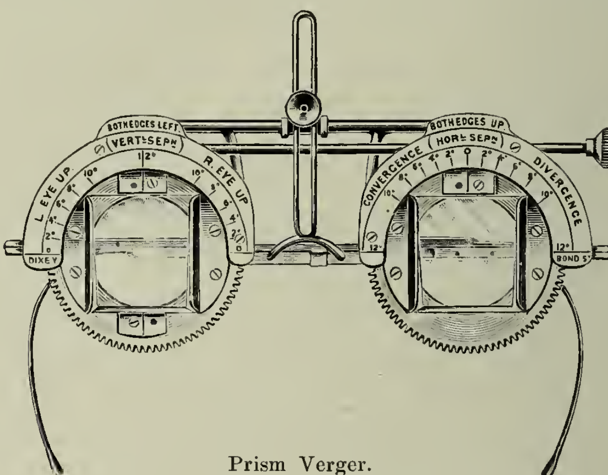
A celluloid arch, graduated in degrees, surmounts each prism. The markings on each arch relate, however, not to the one prism only, but to the two jointly, one arch being used for horizontal vergence, and the other for vertical vergence. A little study of these arches will make the use of the instrument self-evident.

To measure horizontal verging power. Start with both prisms edge up, with their indices pointing to zero. Both visual axes are now equally deflected upwards by the full strength of each prism, viz., 6°, but they experience no lateral deflection. Direct the patient's attention to a candle flame, Snellen's test types, or any distant object at the distance of, say, 6 metres or more, requesting him to notify the first appearance of double vision. Rotate the milled head counterclockwise; then the index will leave zero and travel outwards along the quadrant marked "divergence."

On the first appearance of diplopia read off the result, which specifies the patient's prism-diverging power in distant vision. Next, rotate the milled head in the opposite direction and discover in a similar way from the numbers of the inner quadrant marked "convergence," his prism-converging power. But in making this convergence test it is important that the patient should signify the moment at which the lowest test types he can read become indistinct, otherwise the test becomes one merely of the total convergence rather than for the relative convergence during accommodation for distance.

To measure vertical verging power. Place the tip of the right forefinger behind the reversible prism, and the thumb on its front face to withdraw it from its fitting. Reintroduce it "base upwards" (so that now one prism has its edge upwards and the other its base

upwards), and rotate the milled head clockwise so as to cause the base of the movable prism to rotate inwards and that of the fixed prism outwards. As soon as the index of the movable prism points to 12° and that of the fixed prism to zero, confine attention to the arch over the fixed prism, which it will be noted relates solely to vertical vergence. As its heading indicates, we have commenced with the edges of both prisms pointing to the patient's left. Now rotate the milled head counter-clockwise until diplopia is awakened; the angle of artificial elevation to the right eye above the left (right supravergence) is read off from the inner quadrant which is marked "right eye up."



Prism Verger.

Rotation of the milled head in the opposite direction, so as to raise the basal index will in a similar manner measure the angle of artificial elevation of the left eye above the right (left supravergence) on the quadrant which is marked "left eye up."

When single vision exists, the vergence power may be increased if we proceed exactly as above, but linger at each point where diplopia threatens, encouraging the patient to exert every effort to maintain single vision while the prisms are rotated through small arcs, so as alternately to relax and stimulate the effort of fusion. The exercise may be varied by letting the frame be worn for half an hour or more at a time, with the prisms so adjusted as to exercise the fusion faculty in any direction in which it may appear deficient.

If the object to get rid of is—

(*a*) *Esophoria.* Start with both prisms edge up and rotate them outwards by turning the milled head counter-clockwise.

(β) *Exophoria.* Rotate in the reverse direction.

(γ) *Hyperphoria.* After reversing the movable prism in the manner previously described, start with both prisms "edges left." To train away right hyperphoria rotate the milled head clockwise, and counter-clockwise for left hyperphoria. It will be noted that when one eye ascends, the other descends at an equal rate, and the figures record the sum of the combined deviation.

The use of the verger to treat slight squints by exercise. Commence with the apices of the prisms pointing in the direction suggested by the squint. Thus, for convergent squint both apices will be inwards, for divergent squint both outwards. For upward squint each prism should start with its edge to the left. Then rotate the prisms so that the edge of each shall seek the direction of the vertical deviation of the corresponding eye until diplopia gives place to single vision. Thereupon slowly rotate the edges back again till diplopia threatens, and there leave them for a short while, adding, if thought well, slight intermittent rotations of small arc. For example, in right upward squint the edge of the right prism would first be rotated upward to secure single vision, and then slowly downward again till on the verge of diplopia. In left upward squint the edge of the left prism should be similarly manœuvred.

The instrument can also be used in much the same way as Risley's double prism. A set of glass rods should be held before one of the prisms (horizontally for testing the horizontal balance, and vertically for testing the vertical balance) at the same time that the attention of the patient is directed to a distant source of light.

In measuring the horizontal balance, start with each prism edge up, and rotate the milled head until the streak of light passes through the flame. The heterophoria is then read off from the quadrant marked "convergence" or "divergence," as the case may be.

To measure the vertical balance, set each prism "edge left," and again rotate the milled head till the streak passes through the flame, reading off the result on the quadrant to which the index points, marked "left eye up" or "right eye up" as the case may be.

It may be remarked that while this instrument, if correctly made, measures hyperphoria with complete accuracy, it is not so suitable for measuring esophoria and exophoria as the use of the rods simply with a tangent scale on the wall.

After abstracting the detachable prism the remaining one can be employed to reduplicate the writer's arrow tangent device for the measurement of horizontal heterophoria in near vision.

Prism-vergence. The power of the ocular muscle as measured by the prism-verger.

Prism, Water. See **Liquid prism.**

Prism, Wollaston. See **Wollaston prism.**

Privileged communications. See **Legal relations of ophthalmology.**

Probe, Lente's. A silver probe having a bulb coated with silver nitrate.

Probes, Lachrymal. See p. 6941, Vol. IX; as well p. 1374, Vol. II; also **Caldwell's lachrymal probes,** p. 1357, Vol. II of this *Encyclopedia.*

Probe-objekt. (G.) Test-object.

Probierleder. (G.) Leather (kid) used in the testing drum, for determining the degree of sharpness of instruments, especially of knives used in ophthalmic surgery.

Probiertrommel. (G.) Trial drum, for testing the sharpness of instruments.

Procain. The name adopted by the Federal Trade Commission as the official designation of novocain. See p. 8384, Vol. XI of this *Encyclopedia.* Julius Stieglitz of the National Research committee thus comments (*Am. Jour. of Ophthalmology,* p. 536, July, 1918) on this subject: It appears that in certain quarters the attitude is taken that the local anesthetic sold as procain is not identical with that marketed as novocain. The Subcommittee on Synthetic Drugs of the National Research Council believes it important that this misunderstanding should be corrected and hence offers the following explanation:

The monohydrochlorid of para-amino-benzoyldiethyl-amino-ethanol, which was formerly made in Germany by the Farbwerke, vorm. Meister, Lucius and Bruening, Hoechst A. M., and sold under the trademarked name novocain, is now manufactured in the United States. Under the provisions of the Trading with the Enemy Act, the Federal Trade Commission has taken over the patent that gave monopoly for the manufacture and sale of the local anesthetic to the German corporation, and has issued licenses to American concerns for the manufacture of the product. This license makes it a condition that the product first introduced under the proprietary name "novocain" shall be called procain, and that it shall in every way be the same as the article formerly obtained from Germany. To insure this identity with the German novocain, the Federal Trade Commission has submitted the product of each firm licensed, to the A. M. A. Chemical Laboratory to establish its chemical identity and purity, and to the Cornell pharmacolgist, Dr. R. A. Hatcher, to determine that it was not unduly toxic.

In conclusion: Procain is identical with the substance first intro-

duced as novocain. In the interest of rational nomenclature, the first term should be used in prescriptions and scientific contributions.

Procatarxis. A predisposing cause.

Processess, Ciliary. Folds or thickenings of the ciliary body arranged radially around its anterior margin, interdigitating with processes of the suspensory ligament of the lens. See **Anatomy of the eye.**

Processes, Ciliary, of the hyaloid. Folds of the hyaloid membrane which dip between the true ciliary processes.

Processes, Ciliary, of the retina. The anterior portion of the retina, which is closely united with the true ciliary processes.

Process, Orbital. A somewhat pyramidal bony process which ascends from the anterior margin of the vertical plate of the palate bone. Its anterior margin articulates with the superior maxilla, the internal with the ethmoid bone, and the posterior with the sphenoidal turbinate bones; the upper aids in forming the orbit, and the external in forming the spheno-maxillary fossa.

Processus falciformis. See **Fishes, Eyes of,** p. 5205, Vol. VII of this *Encyclopedia.*

Prochaska, Georg. Born at Lipsitz, in Moravia, he studied at first philosophy, then medicine. In 1776 he received his medical degree at the University of Vienna, and at once became assistant to Beer. In 1780 he removed to Prague in order to accept the chair of anatomy in the university at that place, but in 1791 was called back to Vienna, where he was made professor of anatomy, physiology and ophthalmology. He died in 1820. He left no writings on ophthalmology, but was a celebrated operator on the eye, having performed, according to some reports, no fewer than 3,000 cataract operations.—(T. H. S.)

Profilassi di Credé. (It.) The Credé method.

Profondeur de foyer. (F.) Depth of focus.

Prognathous. Having the jaws projecting forward, as in most apes; having the gnathic index above 103° or the profile angle below 89°, or Camper's facial angle below 80°.

Prognosis, Ophthalmic. This subject is of the same importance in ophthalmology as it is in other branches of medicine, and is discussed as a part of hundreds of captions in this *Encyclopedia*, especially under **Legal relations of ophthalmology.** In this section a typical discussion only will be given, as set forth in the paper by P. H. Adams (*British Jour. of Ophthal.*, p. 161, March, 1917) on the relations of vascular disease of the retina to the duration of life. He remarks that the most numerous cases of general medical interest that attract the attention of ophthalmic surgeons are those that have some form or

other of disease of the vascular system. It is by no means unusual for the failure of vision to be the first symptom that obtrudes itself on the notice of the patient, and sends him to seek advice of the eye specialist. These cases one examines and finds various pathological manifestations in the retina, returns them to their general medical adviser for treatment, and not infrequently loses sight of them henceforth, or else they attend the hospital, are put on to potassium iodide, and attend for a variable length of time, and then are no more seen.

With the idea of finding out what happens to these patients and when, Adams undertook an inquiry and endeavored to trace the end of such cases. At first he imagined the majority of them would be dead, and accordingly first applied to the various registrars for details, but meeting with somewhat poor results, next sent reply-paid postcards to the patients themselves, inquiring after their health, and was very agreeably surprised to find a number who were still living.

The types of retinal lesions he selected were flame-shaped hemorrhages and signs of vascular disease in the retina, venous thrombosis and hemorrhagic retinitis, "embolism" of the central artery, retinitis circinata; in fact, all those conditions usually associated with the condition of arterio-sclerosis. He purposely omitted true albuminuric retinitis, as the fate of such patients is well-known. A few cases of diabetic retinitis crept in accidentally and a few traumatic hemorrhages, but these latter have not been included in the statistics.

In one way or another he collected 159 cases from the records, and traced 124 of them; of the total number 63 were males, the remainder 96 females—58 of them married and 38 single.

To examine more accurately the prognostic influence of these lesions, he arranged the cases according to their ages, taking, first, cases under 50, the majority being between 40 and 50; then, cases between 50 and 60; then those between 60 and 70; next, those between 70 and 80; and, lastly, those over 80.

Considering the first group, cases under 50 years of age. These number 26, and of these 18 are women and 8 men.

One finds a remarkable difference in the length of life in the various cases, and this difference is seen to be due to the presence of albumen in the urine.

For example—of those with albumen present:

Two died after five years, one of cerebral hemorrhage, the other of phthisis.

One died after three years ten months, of chronic Bright's disease.

One died after three years five months, of nephritis.

One alive after two years three months.

One died in three months, of granular kidney.

One died in four months, a syphilitic subject.

One alive after six years, in spite of a blood pressure of 220 mm., but comparing these with those that had no albumen, one finds:—

One living after 28 years. Age 74.

One living after 25 years. Age 40. (Case of embolism.)

One living after 17 years. Age 66.

One died after 16 years of cerebral thrombosis, pneumonia, and heart failure, at the age of 67, but he had four strokes.

One living after 15 years. Age 50.

One living after 11 years. Age 55.

One living after 4 years. Age 48.

In many of the cases he had no note as to the state of the urine; but in young patients with vascular disease of the retina, the presence or absence of albumen in the urine is by far the most important factor in forming an opinion as to the prognosis *re* life.

The cases between 50 and 59 number 47, of whom 28 are women and 19 men.

The difference in prognosis between those with and without albumen is not so marked as in the preceding group. Whereas in that group the longest life with albumen was six years, many in this one have lived a considerable time.

One case at the age of 58 had flame-shaped hemorrhages in the left eye, and some albumen in the urine. She is still alive, age 71—13 years after the original lesion. Another lived nine years, dying of syncope, age 63. She had hemorrhagic retinitis and thickened arteries.

Another case of interest is a man who had a vitreous hemorrhage, arteries enormously thick, blood pressure of 200, and a good deal of albumen in the urine. When first seen he was quite broken down, could not manage his business, and was altogether in a most tottery condition. After 18 months his vitreous hemorrhage had practically cleared up; he was altogether better and brighter in himself; and he had had a severe attack of appendicitis, with bad operation, in the meantime.

Of cases without albumen, two died under two years; one of them had a blood pressure of 200 mm. and died of a stroke. Others died at 4, 5, 6, and 12 years respectively. Many of the rest were alive at times varying from 1½ to 16 years, the latter being a woman who had extensive retinal hemorrhage at the age of 54, and who was still alive,

age 70; although she was beaten by a man with hemorrhagic retinitis at the age of 54, but no albumen, who was still alive, age 76; 22 years after the original lesion.

Cases developing between 60 and 69 number 54, and are evenly divided, 27 females and 27 males. As before, cases with albumen compare unfavorably with those without.

Examples of cases with albumen:

One died in four years with cardiac asthma.

One died in six months with a stroke.

One living after three and a half years, but in poor health.

One living two years, age 66.

One living three and a half years, age 68.

Comparing these with those known to have had no albumen:

(114) Retinitis circinata R.E. at the age of 67. Retinitis circinata L.E. at the age of 66 and much hemorrhage. Still alive and well after 10 years. Another died after six years, age 70.

(80) Had a blood pressure of 250 at the age of 64, with flame-shaped hemorrhages. Died four and a half years later, old hemiplegia and acute bronchitis.

(84) Had hemorrhages in the left eye followed by glaucoma twenty-five years ago, and was still alive, age 84.

(85) Another at 65 years, who had venous thrombosis, died of senile decay, aged 81, sixteen years later.

(91) At 68 years, thickened arteries and ? embolism, died at the age of 78 of cerebral hemorrhage, about ten years later; and so on.

Thus at this age the prognosis *re* life of retinal vascular disease is, on the whole, extraordinarily good, the normal expectation of life at 60 being roughly 13½ years, and at 69 nearly 9 years.

Cases between 70 and 80 number 26; 20 females and 6 males. They show the remarkable age to which these patients live.

(129) Age 75, male, with much albumen. Hemorrhages and thickened arteries, was still alive, age 83, after 8 years.

Other cases are:—Alive, age 75, after 2 years; 77, after 5 years; died at 83, after 10 years; died at 79, after 8 years; alive at 75, after 5 years.

(136) Alive at 80, living 8 years and 3 months.

(139) Alive at 80, after 6 years.

(143) Blood pressure 220, no albumen, died aged 78, of a cerebral hemorrhage, living 5½ years.

(145) Hemorrhage at age of 75, alive at 82, after 7 years.

(149a) Vascular disease and diabetic retinitis, alive after 5 years, age 78.

One other case is a man (No. 75) who had both albumen and sugar at the age of 60, and who lived for 7 years before his death, cause unknown.

Finally, cases 80 years of age and over.

There are 5 of these cases—3 men and 2 women.

(151) Age 87, with hemorrhage, died, aged 93, of senile decay.

(152) Age 81, with albumen and hemorrhage, still alive, aged 86.

(153) Age 86, embolism, died, aged 89, of cerebral hemorrhage.

(154) Age 80, hemorrhage and thickened arteries, still alive, aged 84.

The fifth could not be traced after seven months, but these few cases bear out the fact that the older the patient, the less important from the point of view of prognosis to life are the vascular diseases of the retina.

As regards use of the eyes, Adams believes that while it is common-sense not to work a damaged organ hard, he has never seen any damage done to these eyes by ordinary use; and as it is a condition which may last more or less to the end of the patient's life, it seems a mistake to prohibit the use of the eyes, as is sometimes done, for, after all, what is the use of having eyes if they are never used?

Lastly, as regards causation. Very many were no doubt due to thrombosis of vein or artery, and in some cases it was difficult to determine exactly which vessel was at fault. "Some years back, after Sir Almroth Wright's suggestion, that many ocular hemorrhages might be due to thrombosis, I measured the coagulation-time of the blood, but, as a rule, rarely found much variation from the normal. Nor is this, I think, to be wondered at. The lesion may have occurred a few days to a few months before being seen, and the coagulation-time is known to vary very rapidly with differences in diet, time of day, length of time after meals, etc. The only thing of interest I did come across was the fact that potassium iodide had by far the most powerful action in prolonging the coagulation time of any drug I tried. In my experience, it was much more potent in this respect than citric acid, and in those cases of iodism where the symptoms are almost if not entirely due to this property, they can, to a certain extent, be obviated by giving calcium at the same time, or, what comes to the same thing, giving it in large doses of milk, as one used to be taught some years before anyone took any notice of coagulation-times.

"This fact, in addition to its power of lowering the blood pressure, makes the drug of real value in the treatment. Other means of lowering the blood pressure, such as electrical treatment, I have been

disappointed in; the effect seems to be only temporary, and blood pressure, after all, is but a symptom, and one that the patient does not object to. One old man, in particular, I remember used to say, 'I'm sure my blood pressure is well over 200; I feel so fit and energetic.'

"Conclusions. Retinal lesions are considerably more common in women than men, and that not altogether due to child-bearing, as 38 of the 96 women were, as far as I could discover, unmarried. The cases were most numerous between the ages of 60 and 70, and next between 50 and 60.

"The older the patient, the better the prognosis as regards life, irrespective of the presence of albumen in the urine to a large extent, whilst the younger the patient, the worse the prognosis, especially so if albumen is present in the urine."

Progressive atrophy of the iris. See p. 6628, Vol. IX of this *Encyclopedia.*

Progressive cataract. Any opacity of the lens which shows a tendency to increase.

Progressive muscular dystrophy. A general term for progressive muscular atrophy, pseudo-hypertrophic paralysis, and some allied affections. See p. 4108, Vol. VI of this *Encyclopedia.*

Progressive myelitis. See p. 8260, Vol. XI of this *Encyclopedia.*

Progressive paralysis. See p. 9358, Vol. XII, of this *Encyclopedia,* under **Paresis, General.**

Progressive ptosis. See **Ptosis, Progressive.**

Projection. A throwing forward, especially the act of referring impressions made on the sense-organs to their proper source, so as to locate correctly the objects producing them. 1. The process of throwing an optical image of an object on to a screen. 2. The *projection of visual impressions* is the faculty or act of projecting out from the fundus of the eye into space the impressions of objects made upon the retina by the rays of light which emanate from them entering the pupil and coming to a focus upon the perceptive layer of the retina. By means of this, objects are correctly located in space. See **Physiological optics.**

Projection, Binocular. The faculty of transposing into space and combining the impressions made by objects in space upon the perceptive layer of the retinæ of both eyes at the same time.

Projection, Erroneous. False projection. A misjudging of the position of an object, due to oculomuscular defects.

Projection latern. (G.) Sciopticon, or projection apparatus.

Projection, Uniocular. Monocular projection. The faculty of transposing or displacing into space the impressions made by objects upon the retina of one eye. The projection is about in the line of direction of the object, but the estimate of the distance of objects in this form of projection is faulty.

Projector, Spectrum. See **Spectrum projector.**

Projectoscope. An apparatus for throwing pictures on a screen by reflected light.

Prolapse of the iris. Protusion of the iris through a wound in the cornea. See **Hernia of the iris.**

Prolapse of vitreous humor. See **Injuries of the eye; as well as Cataract, Senile.**

Prolapsus corneæ. An old term for staphyloma of the cornea.

Prolapsus iridis. Hernia or prolapse of the iris.

Prolapsus oculi. Exophthalmia.

Prolapsus palpebræ. (Obs.) Ptosis.

Prolapsus scleroticæ. (Obs.) Staphyloma of the sclera.

Prolasso del corpo vitreo. (It.) Prolapse of the vitreous.

Prominentia oculi totius. Exophthalmia.

Prophylaxis in ophthalmology. As with prognosis, a discussion of this term naturally appears with the caption devoted to individual diseases. At once, however, one thinks in this connection of dangerous operations, for cataract, glaucoma, etc., of gonorrheal and sympathetic ophthalmia and of myopia—all of which are considered under their proper rubrics in this *Encyclopedia.* See, also, **Conservation of vision, Blindness, Prevention of, Gonorrhea, Ocular relations of, Bacteriology of the eye,** etc., in this *Encyclopedia.*

Propol. A proprietary disinfectant for wounds and instruments.

Proptoma palpebrarum. (Obs.) A synonym of ptosis.

Proptometer. An instrument for measuring protrusion, especially, a scale for measuring the amount of exophthalmos.

Proptosis. Exophthalmus. Protrusion of the eyeball. See p. 4850, Vol. VI of this *Encyclopedia.*

Proptosis oculi. A name given by Celsus to an exophthalmia.

Proscolex. The embryo of the ovum (cysticercus).

Prosopalgia. See **Neuralgia of the fifth nerve,** p. 8393, Vol. XI of this *Encyclopedia.*

Prosopanometer. An instrument for taking various measurements of the face in adjusting spectacles and eyeglasses.

Prosopantritis. Inflammation of the frontal sinuses.

Prostatitis in ophthalmology. Doubtless in a very small percentage of cases urethral and prostatic infections—both acute and chronic—

affect (mostly indirectly) the ocular apparatus. Of these metastatic processes iritis is much the commonest.

As a contribution to the study of focal infections as causes of ocular disease P. H. Dernehl (*Ophthalmology,* July, 1915) remarks that the etiology of iritis, following in the wake of a gonorrhea when the iritis is associated with or appears as a direct sequela of a urethritis, is readily established; the more so if signs of a more general systemic gonorrheal infection are in evidence. But when it occurs independently of and in absence of any genito-urinary symptoms or when the interval which has elapsed between the initial gonorrheal infection and the subsequent iritis has been so long, that the relation of the former as a progenitor of the latter is entirely lost sight of, the vague and nugatory term of idiopathic or rheumatic iritis is usually applied, particularly as a history of previous "rheumatism" or joint pain can frequently be elicited.

Regarding the clinical entity of such form with its masked etiology opinions are widely divergent. Its actuality as a gonorrheal iritis is denied by some and modern teaching appears to regard such late form as a rare disease.

Fuchs and de Schweinitz in their report at the International Medical Congress, in London, in 1913, upon chronic uveitis, exclusive of luetic, tuberculous and sympathetic forms, express the opinion that the gonococcus plays a very minor rôle in these late chronic forms, but that a rheumatic etiology is very doubtful.

Goldzieher believes that chronic gonorrheal iritis is much commoner than is generally supposed and places it next to luetic iritis in frequency of occurrence, and that many cases of so-called rheumatic iritis can upon careful study be shown to be gonorrheic in origin, with shreds and organisms in the urine. That we still stand upon the threshold of our knowledge regarding the etiology of these cases and that increased perfection in our methods of examination will bring forth greater objective evidence and light is certain.

Griffith reports a series of cases of gonorrheal iritis all males in which iritis followed from four to fifteen years after the primary gonorrheal infection. Bacteriological examinations were not made. He is of the opinion that a great many of the cases of so-called rheumatic iritis are gonorrheal in origin.

Beaumont saw at the Royal Mineral Water Hospital 20 patients from 1888 to 1907, who came there as victims of either gout or rheumatism or rheumatoid arthritis and who suffered from either acute or subacute iritis, two of these were females, eighteen were males, sixteen out of the twenty confessed to having had gonorrhea. Of these one

gave a history of having had the infection one year ago, one fifteen years ago, one ten years ago. The remaining cases reported a shorter time. Bacteriologic examinations were not made. He is of the opinion that rheumatic iritis is a very rare disease, and that critical inquiry in many cases will demonstrate a gonorrheal arthritis, and the associated iritis depending for its etiology upon a gonorrheal focus.

Prosthesis, Ocular. See **Prothesis.**

Protanope. A red-blind person.

J. H. Parsons (*Introduction to the Study of Color Vision*, 1915) accepts the descriptive terms protanope for red, deuteranope for green and tritanope blue blindness; but there are other forms of color-blindness, reaching even to totality or monochromats.

Protanopia. Von Kries' term for red-blindness, as indicating a defect in the first constituent necessary for color vision.

Protargol. Protargolum. A compound of albumen and silver, appearing as a yellowish powder with a slightly metallic taste, soluble in its own weight of water. The solutions are decidedly brown, are fairly permanent but ought to be protected from light. It is a mild bactericide, is non-irritant and, clinically, closely resembles argyrol.

On the whole, this argentic compound has proved to be one of the most popular of the substitutes for silver nitrate in ophthalmic therapeutics. In gonorrheal ophthalmia—infantile and adult—and in all the milder forms of conjunctival infection it has been praised by numerous observers. For example, Kramer found, in one hundred cases where the Credé method was used, that inflammatory reaction occurred ninety-six times; more than once it was followed by profuse secretion which persisted for several days. In 80 per cent. of the cases there was increased secretion; in 50 per cent. it disappeared after a day and in 4 per cent. it lasted until the fourth day. There was no reaction after 25 per cent. protargol, while protection seemed as perfect as with 2 per cent. silver nitrate.

Calvin R. Elwood at first found this drug in 5, 10, or 15 per cent. solutions so irritating that he abandoned its use. For the past few years it has been his custom to have a 50 per cent. solution made up, without any trituration, and placed in an ice-box for twenty-four hours. At the end of this time a complete solution is formed which has been very serviceable to him as a conjunctival application and very seldom causes any irritation.

A. D. McConachie prefers, when prescribing protargol to use himself, 1 per cent. silver nitrate, with 10 per cent. solution of protargol to be used at home every three or four hours. He precedes both the office and home treatment by irrigation with normal salt solution or 1-8000 of sublimate.

Since the appearance of argyrol, argentamine and other organic silver compounds the popularity of protargol seems to be on the wane. Probably it is quite as effective, or ineffective, as silver vitelline in gonorrheal ophthalmia and may be equal to it in the same dosage (5 to 20 per cent.), or 20 to 50 per cent., in the treatment of the bacterial conjunctivitis of corneal infections. (See **Silver salts** and **Argyrol.**)

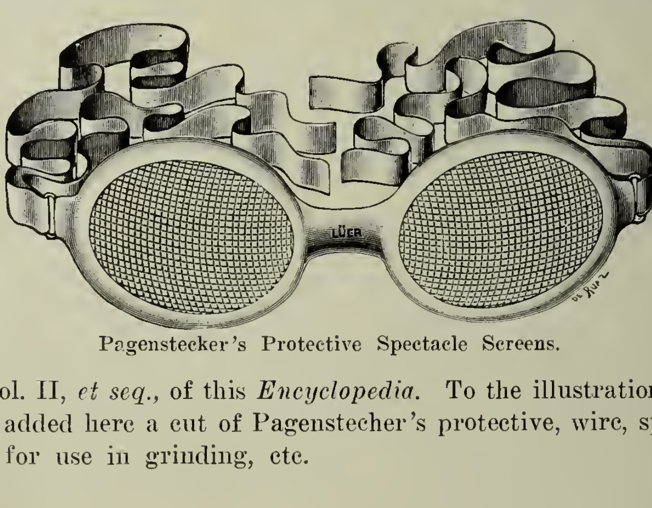
More than one case of blindness has followed the injection of this almost useless drug into the lachrymal sac. For example, a woman of 50, who was suffering from an acute phlegmon of the sac which had ruptured on the face, was treated by Park Lewis (*Prac. Medicine Series,* Eye, p. 144, 1909) in the usual manner until inflammatory symptoms subsided somewhat, when probing was begun and the passage syringed with 25 per cent. protargol. No reaction followed until this was done the second time. Two days later she 'phoned that great pain came on shortly after leaving the office and that the eye was blind. She was at once directed to return, when the eye was found proptosed from an orbital cellulitis. Pupil was dilated and immobile. No light perception. The soreness and swelling gradually disappeared, leaving the eye blind from optic atrophy. It is presumed that the cellulitis was induced by some of the protargol escaping from the sac into the orbital tissues.

See, also, **Argyrol**; as well as **Argyrosis oculi.**

Protective bandages and dressings. See p. 149, Vol. I of this *Encyclopedia;* as well as such rubrics as **Eye protector** and **Eye shade.**

Protective coloration. See **Coloration, Protective.**

Protective glasses. This subject is pretty thoroughly discussed on p.



Pagenstecker's Protective Spectacle Screens.

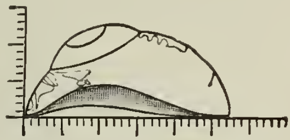
1161, Vol. II, *et seq.,* of this *Encyclopedia.* To the illustrations there may be added here a cut of Pagenstecher's protective, wire, spectacle screens for use in grinding, etc.

Protesi. (It.) Protheses.

Proteus. A genus of cave-dwelling, tailed amphibians with persistent gills. From their habitat the eyes are very imperfectly developed, and only slightly sensitive to light. A nearly related genus, Necturus, lives in N. American rivers and lakes.

Prothesis, Ocular. Prosthesis. Artificial eye. Since the section on **Artificial eyes** was written (1913) a number of additional observations on the subject have appeared in print, some of which are set

Measurement for Width of Artificial Eye.



Measurement for Length and Height of Artificial Eye.

forth here. The reader is also referred to Wood's *System of Ophthalmic Operations*, Vol. I, p. 457.

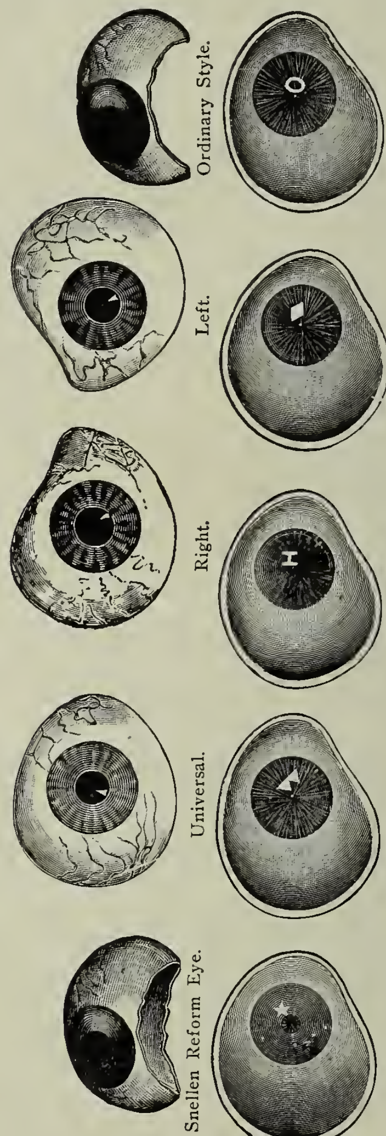
Exact measurements for the prescription of artificial eyes are of extreme importance when one has not ready access to a neighboring optician. Comparisons with a boxful of numbered samples corresponding to the stock list of a dealer has already been referred to as a

Interim Protheses.

method of ordering protheses from a distance; the accompanying cuts suggest another means.

Interim protheses are hollow bodies of acid-proof glass with a central passage for the discharge of secretions and excretions. Inserted

directly after the enucleation or evisceration, they prevent irritation by the eyelashes, promote healing and the formation of a normal

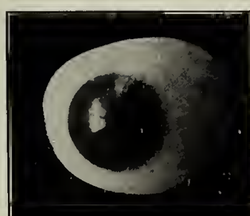


Various Types of Artificial Eyes.

cavity and central disposition of the muscular stump. They can be repeatedly used after being boiled. See the cut.

Celluloid film as artificial conjunctiva and ocular prothesis. Kaz (*Wochenschr f. Therap. u. Hyg. d. Auges*, Jan. 2, 1913) describes a case of total ankylosymblepharon in which the introduction of a celluloid film behind the lids acted very favorably, being followed by disappearance of granulations and enlargement of the cul-de-sac. The film was well borne by the eye. Subsequently he inserted a film prothesis, consisting of two layers of celluloid enclosing a piece of very fine silk upon which he had an iris sketched. The cosmetic result was a good one, as on account of the transparency of the film it was hard to tell that there was any scleral covering.

While subsequent suppuration necessitated removal of the prothesis, the case suggests three possible uses of the celluloid film: 1. As a corneal bandage in keratoectasia and staphyloma, as a substitute for



Shell-shaped Prothesis with Full Cornea for X-ray Diagnosis. (Wessely.)

Kuhnt's conjunctival plastic, as a means of separating a trachomatous pannus from the upper lid. 2. As a protection against symblepharon, by plain film protheses. 3. As a prothesis in total leucoma instead of tattooing.

Improvised prothesis. A man, 69 years of age, had one eye removed in 1892. He was found by Fenton (*Prac. Med. Series*, Eye, 1910) to be wearing a prothesis made of the half of a prune pit, shaved smooth (with a pocket knife) on the edges. The cornea was represented by a pearl button being set in the front of the prune pit.

T. J. Dimitry (*Annals of Ophthal.*, April, 1917) has suggested an improvement in the Snellen eye adapted from the plate used by dentists to which the teeth are attached. The plate of hard rubber when properly fitted to the roof of the mouth has a concavity which produces a degree of suction during the time of swallowing, and is thus held in position.

An artificial eye made of glass is used, the different shapes and contours being just as in the improved eye of Snellen, but on the posterior surface there is an opening about four to twelve millimeters in size. The aim is to produce a moderate suction through the vacuum

occasioned by the working of the lids. Rough edges are to be avoided, so as not to injure tissues. In a properly adjusted eye, of correct size and shape, it will grasp the tissues and procure an effect much to be desired.

Spontaneous explosion of Snellen artificial eyes. Rochester (*Ophthalmic Record,* May, 1916) having had a case of this nature made an exhaustive inquiry to ascertain its frequency and causes. He reived replies from twelve colleagues reporting to him eighteen explosions occurring in patients using this kind of eye. As a rule the accident comes when the patient is engaged in some normal occupation. He suddenly hears a report as if a pistol were shot off in close proximity to his head. At the same time he feels a sharp pain in the orbit, and finds the lids covered with blood, and is quite frightened. The orbits in these eighteen cases did not sustain serious injuries. In 88 per cent. of the cases there was some abrasion of the conjunctiva, varying from a slight cut to deep lacerations. Many pieces of glass were found in most of the cases, imbedded in the soft membranes, and had to be extracted. Two of the patients lost consciousness. With a view to ascertain the cause of the explosions, the manufacture of the eyes was studied finding that the sealing of the back of the piece was made while at a white heat, with the result that a partial vacuum takes place in cooling and therefore a continuous atmospheric pressure is exerted on the outside of the finished eye. A sudden change of temperature of the globe, or a decided inequality in the temperature of different parts of the same, produces unequal expansion or contraction and renders the glass less able to withstand the atmospheric pressure. Another deficiency of these eyes is their susceptibility to the destructive effects of orbital discharges. Twenty-eight per cent. of the eighteen patients referred to had the accident two times, which can be accounted for by the deleterious influence of the secretions on the glass of the shell.

Prothesis after exenteration of the orbit and in extensive destruction of the neighboring tissues of the nose and face, especially those *due to high explosives.* As pointed out by the *Keystone Magazine,* in the present war soldiers are returning from the line of fire not merely with an eye shot out, but with the entire lid and eye socket destroyed, and the absence of these foundations has often made the insertion of an artificial eye impossible. Until the present moment there has never existed any means for concealing this disfigurement and restoring to the unfortunate victim the appearance of a normal man possessing two eyes. But quite recently a French surgeon, Henri

Einius, has made it possible to do this even when the eyelid is entirely missing.

In its essential features the apparatus consists of an artificial eye, equipped with a lid of any convenient plastic material—paraffin or moulding paste, colored to match the subject's complexion. This eye is also furnished with lashes, to give to it, to the fullest possible extent, the appearance of a natural eye. It derives its support from fine metal wires attached to eyeglass or spectacles, so adjusted that when the latter is placed upon the nose, the artificial eye falls accurately into its cavity. The eye may easily be separated from these attachments for cleaning.

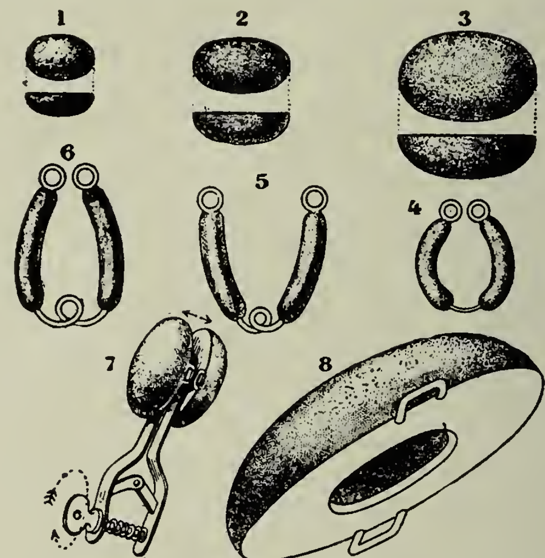
In case it is desired to have a somewhat stronger pressure upon the ocular cavity, the supporting wires may be replaced by light springs of toric or other shape; and in pursuit of a similar goal there may be inserted, behind the artificial lids, a washer of elastic gum to prevent the entrance of dust. See, also, **War, Ophthalmic medicine and surgery in.**

War wounds of the eye requiring special protheses. The *Ophthalmic Year-Book,* p. 275, 1916, gives the following account of this subject.

On account of the war a larger number of enucleations are done, and the need of improving the technic of prothesis is strongly felt. The orbital cavities, due to the ravages of projectiles, undergo great destruction, are irregular, with contracted or insufficient cul-de-sacs, or crossed by cicatricial bands which make the insertion of a standardized glass eye impossible. Cosse, Lemaitre and Teuillières, Valois and Rouveix have made extensive trials to obtain mouldings of the orbital cavity, in order to prepare an eye specially suitable for each wounded, so that it may possess a good esthetic aspect, follow the movements of the relics of the stumps and avoid the sunken appearance of the globe. Cosse appealed to different substances and after repeated trials with liquid paraffin and spermaceti found the "crown composition" used by dentists to be the best adapted for that purpose. Lemaitre and Teullières praise plaster, or rather alabaster; Valois and Roubeix prefer plaster of Paris. The first author uses only the fingers to introduce the softened composition into the orbit and presses it by gentle massage into the corners of the orbit. Lemaitre and Teuillèires employ a special impression tray, provided with a small funnel having a large aperture for the admission of liquid plaster; and opposite to it a convex surface intended to reproduce the internal surface of the lids and keep them in their original position. The last named authors use another kind of tray which reproduces the curvature of the anterior surface of the eyeball. The apparatus of Coulomb,

which is made of two valves convex forward and a metallic tube in which the tip of a syringe containing the plaster is fixed, has also been used.

The mould thus obtained reproduces faithfully the details of the orbit. From it a cast is made in caoutchouc, the anterior part being of vulcanite, on which is placed the façade, made of enamel or other suitable material and reproducing the anterior aspect of the eye. The posterior and lateral parts are made in soft rubber and a space is kept between the anterior and posterior walls to be occupied by air



Devices to Restore the Socket. (Valois and Rouveix) No. 1, 2, 3, Ebonite "olives" to be worn. Nos. 4, 5 and 6, Spring dilators of different sizes. No. 7, Screw dilator for rapid dilatation. No. 8, Rubber cup to retain the "olives" in position.

and act as a pneumatic cushion. The retaining action of the lids is exerted on the rigid anterior part of the prothesis. The conjunctival cavity as studied by Valois and Rouveix transforms itself incessantly under the influence of the movements of the bottom of the orbit and changes are produced in the shape of the socket by the constant folding and unfolding of the fornices. The cavity has therefore: 1st, movements of a part of its surface, 2d, transformations of shape of the remaining portions. The prothesis must be built for the best utilization of the movements, and the neutralization and absorption of the transformations of shape. The rubber prothesis is esthetic,

highly elastic, maintains the contact between the lids and the back of the cavity, is unbreakable and is low priced.

Valois and Rouveix claim to have had brilliant results in rebuilding orbital cavities in which it was difficult to insert even a small prothesis, by means of gradual dilatation. They have resorted to ebonite "olives" of different sizes, cut in half and with perfectly smooth edges (see fig.) which are introduced in the socket every day and kept in place by means of a bandage. To avoid dilatation of the lids a ball of rubber is applied over them and pressed against the olive with the bandage.

For rebuilding the cul-de-sac the authors use small ebonite dilators, the shape of a speculum, which are fitted with rings to allow them to be placed in the orbit with forceps. When the cul-de-sacs have been remade, successive sizes of the ebonite olives must be used to complete the dilatation of the cavity. Fibrous tissues give way easily with this method, but it is necessary to maintain the dilatators in the orbit until the prothesis is made, because the dilatation is easily lost.

Cosse speaks also in favor of the therapeutic value of wearing provisional protheses of increased sizes in causing absorption of the cicatricial tissues and the remodeling of a new socket.

In occlusion of the orbit and suppression of the eyelids Rollet employs an orbito-palpebral prothesis made out of wax and rubber. The elastic paste is composed of: Water, 25; glycerin, 62; glue, 5; white gelatin, 20. This paste is colored with ochre and vermilion, in order to obtain the color of the skin. It is applied with a mixture of ether, mastic and fir balsam. A shell of vulcanized rubber with an oval opening for the reception of an artificial eye is constructed, and the artificial eyelids made of rubber, with cilia made of horse-hair, are adjusted to the paste. The patient is himself able to make the apparatus, after having received a plaster mould of his orbital imprint. Coulomb and Ruppe reported six cases in which artificial orbital protheses were made out of dental rubber, and held in place with the help of spectacle frames, ingeniously fastened to the prothesis.

The work of Valois and Rouveix just described is so important that a translation of their article (*Am. Jour. of Ophthal.*, Jan., 1917) is here given.

Ocular prothesis as it was conceived in the limited conditions before the war corresponds very poorly to the necessities created by the numberless injuries which we have to deal with at present.

Formerly it was sufficient to reconstruct the "façade" of the stump of an eye in place or of one reconstructed by the operative ingenuity of the surgeon. This "façade" very esthetically covered the surface

on which it rested, received its movements and was placed in the same plane as the eye still existing. Aspect, movements, projection, all this was realized in this manner. Usually there was a collection of ready-made eyes in series sufficient to satisfy the three conditions. Rarely some case demanded the making to measure of an artificial eye, or on a mould. These were mostly people who were so situated that they could demand a more esthetic appearance according to their fortune.

To-day these rare cases have become the general ones. The collaboration between the prothesist and the surgeon is no longer possible. The prothesis alone must suffice to repair the lamentable destruction which only too often concerns the globe, the adnexæ and almost always the orbit. The ocular prothesis has become an orbital prothesis.

The "façade" is no longer sufficient; this formerly ocular prothesis has become the veritable prothesis. We shall speak of the principles, the laws, the materials of this latter of which we make use to give our wounded heroes an esthetic aspect which will permit them to gain their livelihood as before.

Projection, aspect, movement, this is the aim of our efforts. In order to reach it we at first tried to make a mould of the orbital cavity. We quickly abandoned substances fusible at a temperature slightly higher than that of the body. The difference between the degree of fusion and that of solidification leaves too little margin to count on a true mould; the least technical error causes a malformed mould.

We have used the only material admitted by the prothesists: plaster of Paris, or rather alabaster, which is well borne by the conjunctival mucous membrane.

Before all the orbital cavities of which a mould is made must be healthy, that is, without conjunctival irritation as shown by chemosis, edema of the lids or secretion.

It is important to get the whole moulding of the oribital cavity in one step, not only of the surface of the orbit, but also of the transition folds. In one word, the whole piece must come out as one. To this end it is indispensable to use a tool which we have constructed for this purpose. It consists of a small funnel with a large opening for the admission of the liquid plaster. On the side opposite to this funnel is a convex part reproducing the inner surface of the eyelids. This part is destined to retain the eyelids in the position which they occupied on the eyeball.

The eyelids thus sustained, the liquid plaster easily fills the whole orbital cavity, and, so to speak, takes the place formerly occupied by the absent eyeball.

The mould thus made is very easily counter-moulded; in this counter-mould we have the exact aspect of the empty orbit with its least details.

This mould can, however, not be used in its totality. Surely it will give us the projection of the eyeball, but while preserving this projection we must select the portions useful to us, especially those which will preserve the greatest number of movements.

Therefore, studying attentively the surfaces of the orbital cavity, we notice that only certain portions of it are moving, others are immovable, others finally are deformed by the influence of movements.

Now only the real labors of the prothesist begin. It is impossible to state fixed rules for this research of the movements which can be utilized, experience alone can guide us. In fact, often enough a band which we at first wanted to remove gives us some movements which the prothesis must make behind it. In other cases, we must seek some mobility in some diverticulum of the conjunctival cul-de-sac. This is a question of experience which it is impossible to formulate in principle, except, use the movements, neutralize the deformities.

When the moulding of the orbital cavity has been done, the final mould can be exactly like it only in the one position in which the cavity has been moulded. The least movement of the fundus of the orbit will suffice to change their relations.

The prothesis must therefore be made in such a manner that these relations are maintained during the smallest movements even. In this way we have by a normal evolution come to know the inconveniences of rigid moulds and to replace them by hollow ones, which are elastic in the parts resting on the ocular stump. These moulds will hug the conjunctival surface in all its changes produced by whatever movements are still preserved.

As said above, the old prothesis covered a stump by a front in the shape of a shell; to-day, in most cases this stump is absent. It is impossible to count on it for sustaining the prothesis. In consequence the lower conjunctival cul-de-sac must support the weight of our mould, whatever it is; unfortunately it will in no way be steadied in the orbital cavity.

We have tried to overcome this inconvenience and to build a prothesis which would not only hug the orbital cavity from which it was moulded, but also maintain its position by itself without being at the mercy of the least movement of the head.

The eyeball is normally fastened in its place in the following manner: the muscles of the eye and the capsule of Tenon hold it in front;

these insertions are opposed to the fat cushion of the orbit which has a tendency to push the eyeball forward. The opposition of these two forces constitutes the best fixation imaginable.

We could only try to reproduce this anatomic condition. In the absence of the muscles and Tenon's capsule we could only think of the eyelids. We had in some manner to replace the fat cushion of the orbit and we did it in the following manner. The anterior portion of the prothetic eye is made of caoutchouc or vulcanite; this receives the "façade," reproducing the appearance of the eye, made of enamel or by any other procedure of painting. This constitutes the interpalpebral portion of the ball; against this rigid surface the opposing force of the lids must act.

The posterior part as well as the lateral ones of the mould are made of soft and elastic caoutchouc. The space between the anterior and posterior walls is empty or rather filled with air.

This apparatus is essentially elastic, pneumatic, and hugs without undue pressure the sinuosities of the orbital cavity, copying its deformities, but transmitting the movements.

Its suppleness helps to maintain an elastic contact between the eyelids and the fundus of the orbital cavity. It will not by its weight, small as it is, fall into the inferior cul-de-sac, nor leave the place assigned to it by the moulding.

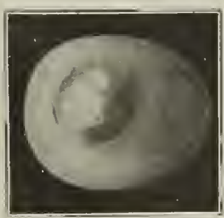
The mould is made of an almost living material, elastic caoutchouc, which transmits the least movements of the eyelids or of the fundus of the cavity; it is in continuous action. This relation is for us the best warrant that it will remain in place; moreover, its lightness helps to assure its stability.

It is useless to discuss how valuable such conditions are to the projection of the artificial eye and to the utilization of the least movements of the remaining muscles, if there are still any to be spoken of as being at our disposal.

It may, finally, not be useless to add that these moulds do not break easily, on account of the material used in their composition. These advantages are of great importance for the wounded who will wear them, many of whom will resume the hard work of laborers.

Three cases of introduction of Schmidt's bone prothesis (osseous spheres) into Tenon's capsule are reported by G. J. Schoute (*Zeitschr. f. Augenheilk.*, Jan., 1915). These spheres were made from the cancellous bone of the head of the femur of the ox, were burned until all organic material had been removed and only a spongy mass of inorganic tissue remained. This was inserted into Tenon's capsule, the muscles sewn over the capsule, and the conjunctiva sutured. In all

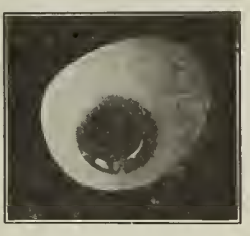
cases the stitches gave way, and the bone spheres became exposed. One case was lost sight of, but in the other two the bone spheres became fixed by granulations which sprouted into the cancellous tissue. The conjunctival defect was very slowly replaced, and eventually a glass eye was inserted. In one instance this was done before the open-



Shell-shaped Prothesis for X-Ray Diagnosis. Cornea with Tinfoil Covering. (Wessely.)

ing in the conjunctiva had healed, but with no evil effect. The cosmetic result was excellent; the artificial eye moved so well that it was almost impossible to detect that it was not a normal eye.

Shell-shaped protheses are also used for X-ray diagnostic purposes. The cuts exhibit the several forms of these, especially the method of



Shell-shaped Prothesis for X-Ray Diagnosis with Ring Cornea. (Wessely.)

showing the bulbar surface and the cornea in the Röntgen image for the purpose of localizing interocular foreign bodies.

Protocatechin, Methyl ester of. See **Guaiacol**, p. 5654, Vol. VII of this *Encyclopedia.*

Protocol. A written statement of the history and treatment of any particular case, especially one made for a medico-legal purpose.

Protocurarin. A poisonous alkaloid derived from curare.

Protometer. An instrument for measuring the forward protrusion of the eyeball; an exopthalmometer.

Protonuclein. Reid Hunt and A. Siedell (Wood's *System of Ophthalmic Therapeutics*, p. 529) thus pay their respects to this proprietary article, occasionally used in eye affections. The remarks also aptly ap-

ply to a number of other agents mentioned in these pages whose owners are apparently undecided whether to seek newspaper notoriety or to attempt to build up a reputation on merit only:

"Protonuclein is a diluted thyroid preparation; samples examined by us, chemically and physiologically, were found to contain the equivalent of 10 per cent. of thyroid containing 0.1 per cent. iodin. (The actual amount of thyroid may be greater or less, as we do not know the percentage of iodin in the thyroid used; but the mixture contained 0.01 per cent. iodin and has one-tenth the physiologic activity of a thyroid preparation containing 0.1 per cent. iodin.) The dose recommended on the bottle is six to twelve grains every three or four hours; this represents six-tenths to one and one-fifth grains of many commercial thyroid powders. The presenee of this thyroid is as skillfully concealed as it is in the case of 'Rengo' or 'Marmola;' yet the amount in a dose does not differ materially in the three preparations. Protonuclein is stated to be a 'Tissue-Builder,' 'Resistant to Toxic Influences, is indieated in all conditions when the organism is below the normal standard.' 'Special conditions; neurasthenia, exhaustion, wasting diseases, anemia, marasmus, malaria, asthenia and as a general antitoxie agent.' It is stated to be 'a perfectly harmless antitoxin, tissue-builder, blood-purifier and digestant;' it 'represents the active principles of life.' Is more claimed for any 'patent medicine' advertised in the daily papers? Yet this is one of the many proprietary preparations the advertisements of which fill the pages of the lower class of medical journals. It must seem to any thinking physician extraordinary adviee to recommend the administration of a preparation containing thyroid, the most powerful tissue-destroying drug known, to patients suffering from typhoid or phthisis—eonditions in whieh the physician is supposed to be exerting every effort to build up the tissues. However diluted the thyroid may be and with whatever other 'active principles of life' (!) it may be mixed, no conscientious physician would care to use it unknowingly."

"Protonuclein, Special" recommended chiefly for local use or internally in half the dose of the ordinary protonuclein is stated to "represent the pure nuclein and nucleo albumen unmixed with milk sugar." It eontains twice as much thyroid as the ordinary powder. Like arbolum, etc., it is stated to be "perfectly harmless."

G. C. Savage has used this remedy as a dusting powder to the eye and conjunctival sac in both conjunctival and corneal phlyctenules and believes it to be of particular value.

Protopsis. Protrusion of the eye.

Protozoic disease of the lids. See **Blastomycetic dermatitis.**